Teck

Fugitive Dust Risk Management Plan

2021 Annual Report

Red Dog Operations
Teck Alaska Incorporated
December 2022

Contents

Acronyms and Abbreviations

CAKR	Cape Krusenstern National Monument
CSB	Concentrate Storage Building
DEC	Alaska Department of Environmental Conservation
DMTS	DeLong Mountain Transportation System
DNR	Alaska Department of Natural Resources
MP	mile post
NANA	NANA Regional Corporation
NPS	National Park Service
OPA	Onion Portage Adventures
PAC	Personnel Accommodations Complex
PMC	Plant Materials Center
RDO	Red Dog Operations
RDTWG	Red Dog Tundra Working Group
RMP	Fugitive Dust Risk Management Plan
T-Dam	Main Tailings Dam
TEOM	tapered element oscillating microbalance
Terramac	Terramac 9T Crawler
TSP	total suspended particulates
TUB	Truck Unloading Building
Tuuq	Tuuq Drilling, LLC
VEE	visible emissions evaluation
XRF	x-ray fluorescence analyzer

Summary

This document presents the 2021 Fugitive Dust Risk Management Plan (RMP) Annual Report for Red Dog Operations (RDO), including the mine, and road and port areas that make up the DeLong Mountain Transportation System (DMTS). The goal of the RDO Fugitive Dust Risk Management Program [overarching goal: *Minimize risk to human health and the environment surrounding the DMTS and outside the Red Dog Mine boundary over the life of the mine*] is to ensure that dust levels remain low using the practices discussed in this 2021 report. This report presents results from efforts related to each of the risk management implementation plans, including the Communication Plan, Dust Emissions Reduction Plan, Remediation Plan, Worker Dust Protection Plan, Uncertainty Reduction Plan, and Monitoring Plan. Activities are summarized below in relation to each of these plans.

The Communication Plan centers around maintaining clear communication with local communities and other interested parties about fugitive dust risk management efforts at the mine. Communication Plan activities during 2021 included community meetings, Subsistence Committee meetings, and communications with other stakeholders and organizations who expressed an interest in mine operations. Details are presented in the section titled "Communication Actions," below.

The Dust Emissions Reduction Plan in 2021 included application of calcium chloride and water on roads to reduce dust, use of the "waterless" air truck wash at the port site, a truck wash located at the mine site in summer months, tailings beach dust suppression, and installation of a new water source for the mine water truck. Details are presented in the section titled "Dust Emission Reduction Actions," below.

Activities related to the Remediation and Reclamation Plan in 2021 involved revisiting previously remediated sites to determine if recovery was progressing in accordance with Alaska Department of Environmental Conservation (DEC) Spill Prevention and Response goals. The Red Dog Tundra Working Group (RDTWG) focuses on rehabilitating spill sites along the DMTS; in 2021, the group met at Red Dog for a site tour and to discuss reclamation studies. Native seed harvest was completed along the DMTS. Details are presented in the section titled "Remediation Actions," below.

Activities related to the Worker Dust Protection Plan include ongoing programs designed to monitor and minimize workers' exposure to dust while at Red Dog, and to facilitate comprehensive communication about these programs, policies, and practices. In 2021, worker health monitoring continued through regular blood lead level testing and by environmental monitoring performed by the on-site Safety & Health department. Strictly enforced policies remain in place to ensure that worker health is protected and that all work environments are safe. Teck Alaska, Inc. (Teck) takes employee health extremely seriously, and noncompliance with health and safety policies is not tolerated. Details are presented in the section titled "Worker Dust Protection Actions," below.

Activities related to the Uncertainty Reduction Plan include research or studies to reduce uncertainties related to the assessment and management of risk to humans and the environment. In 2020, a white paper was prepared to update the state of knowledge based on soil bioaccessibility testing at RDO. The draft paper was provided as an appendix to the 2020 Annual Report. Comments were received back and responses are included in this report.

Activities related to the Monitoring Plan are intended to provide the necessary operational and environmental monitoring data to facilitate continued reduction of fugitive metals and dust emissions, verify the continued safety of caribou and other subsistence foods and water, as well as the health of ecological environments and habitats in the vicinity of the mine, road, and port. In 2021, monitoring activities proceeded on schedule, and statistical analyses were performed on multi-year data sets to identify and evaluate trends and patterns. In 2021, the following monitoring programs were implemented:

- Visual emissions evaluations
- Source monitoring at the mine and port with real-time air samplers
- Real-time alarm system monitoring for dust at the mine
- Road surface monitoring to assess tracking of metals
- Dustfall jar monitoring at the mine, road, and port

Along the DMTS road, trends in concentrations of lead and zinc concentrations have either decreased significantly or show no change. At the mine and port site, trends in lead and zinc concentrations have significantly increased over the past four-year period. The 2021 results indicate some increases noted

over the last four-year period, indicating that additional attention to potential dust controls will need to be considered in 2022.

Introduction

In accordance with the Fugitive Dust RMP (Exponent 2008), the purpose of this report is to provide a summary of risk management activities conducted at the Red Dog operation in the prior calendar year.

Background

The Red Dog Mine is approximately 50 miles inland of the Chukchi Sea, in the western end of the Brooks Range of Northern Alaska. The mine is located on land owned by the NANA Regional Corporation (NANA) and operated by Teck. Base metal mineralization occurs naturally throughout much of the western Brooks Range, and elevated zinc, lead and silver concentrations have been identified in many areas (Exponent 2007). The Red Dog Mine has been in operation since December 1989.

At the mine, ore containing lead and zinc sulfides is mined and milled to produce lead and zinc concentrates in a powder form. These concentrates are hauled year-round from the mine via the DMTS road to Concentrate Storage Buildings (CSBs) at the port, where they are stored until being loaded onto ships during the summer months when the port is ice-free. The storage capacity allows mine operations to continue year-round. During the shipping season, the concentrates from the storage buildings are loaded into an enclosed conveyor system and transferred to the shiploader, and then into barges. The barges have built-in and enclosed conveyors that are used to transfer the concentrates to the holds of deepwater ships. The DMTS road passes through the Cape Krusenstern National Monument (CAKR), which is managed by the National Park Service (NPS). A study conducted by NPS in 2000 found elevated levels of metals in moss near the DMTS road, declining with distance from the road (Ford and Hasselbach 2001).

In response to the results from the NPS study, Teck conducted studies to characterize the dust issue throughout the mine, road, and port areas, and subsequently conducted a human health and ecological risk assessment (Exponent 2007) to estimate possible risks to human and

ecological receptors[1] posed by exposure to metals in soil, water, sediments, and plants and animals in areas surrounding the DMTS, and in areas surrounding the Red Dog Mine ambient air/solid waste permit boundary and port site. The human health risk assessment evaluated potential exposure to DMTS-related metals through incidental soil ingestion, water ingestion, and subsistence food consumption under three scenarios: 1) child subsistence use, 2) adult subsistence use, and 3) combined worker/subsistence use.

The human health risk assessment, including the subsistence foods evaluations, found that it was safe to continue harvesting of subsistence foods from all areas surrounding the DMTS and mine, including in unrestricted areas near the DMTS, without restrictions. Although harvesting remains off limits within the DMTS, human health risks were not elevated even when data from restricted areas were included in the risk estimates.

The ecological risk assessment evaluated potential risks to ecological receptors inhabiting terrestrial, freshwater stream and pond, coastal lagoon, and marine environments from exposure to DMTS-related metals. The ecological risk assessment found that:

- In the tundra environment, changes in plant community composition (for example, decreased lichen cover) were observed near the road, port, and mine, although it was not clear to what extent those effects may have resulted from metals in fugitive dust, or from other chemical and physical effects typical of dust from gravel roads in Alaska.
- The likelihood of risk to populations of animals was considered low, with the exception of possible risks related to lead exposure for ptarmigan living closest to the port and mine.
- No harmful effects were observed or predicted in the marine, coastal lagoon, freshwater stream, and tundra pond environments, although the potential for effects to invertebrates and plants could not be ruled out for some small, shallow ponds found close to facilities within the port site. However, no evidence of adverse effects

[1] Plants and animals

was observed in these port site ponds during field sampling conducted as part of the risk assessment.

Subsequent to completion of the risk assessment, Teck prepared an (RMP) designed to minimize the potential for effects on human health and the environment over the remaining mine life and beyond (Exponent 2008).

Risk Management Plan Overview

Based on the results of the risk assessment and stakeholder input on risk management objectives, the RMP was developed to combine and build upon prior and ongoing efforts by Teck to reduce dust emissions and minimize potential effects to human health and the environment over the life of the mine. Specifically, the overarching risk management goal is to: *Minimize risk to human health and the environment surrounding the DMTS and outside the Red Dog Mine boundary over the life of the mine*.[2]

Although human health risks were not found to be elevated, and potential ecological risks were found to be limited, conditions may change over time, and this possibility was also considered in the design of the RMP. Future changes in conditions and in potential human and ecological exposures over the life of the operation can be addressed through implementation of risk management, dust emissions control, and monitoring activities. More specifically, the RMP established a set of seven risk management objectives (Exponent 2008), which formed the basis for preparation of six implementation plans. Each of the six implementation plans addresses one or several of the overall objectives of the RMP (Figure 1) and includes the planned scope of work to achieve the objectives.

This annual report assumes that the reader has some familiarity with the Fugitive Dust Risk Management Program and is therefore not intended to be a thorough discussion of that program, nor is it intended to provide complete background on either the risk management program or risk assessment that led to the development of the RMP. To develop a more

[2] The mine closure and reclamation plan addresses risk management within the mine solid waste permit boundary (collocated with the ambient air boundary, see Figure 3).

thorough understanding of the risk management programs, interested parties are encouraged to review the human health and ecological risk assessment documents (Exponent 2007), as well as the RMP (Exponent 2008) and its component implementation plans:

- Communication Plan (Exponent 2010)
- Dust Emissions Reduction Plan (Exponent 2011a)
- Remediation Plan (Exponent 2011b)
- Worker Dust Protection Plan (Exponent 2011c)
- Monitoring Plan (Exponent 2014)
- Uncertainty Reduction Plan (Exponent 2012)

These plans are available for review under "News and Related Documents" at http://www.teck.com/operations/united-states/operations/red-dog/.

Data Collection and Reporting Objectives

The risk management program includes collection of large amounts of data for the various implementation plans (discussed below) that are intended for either operational or regulatory purposes. Data collected for operational purposes are intended to provide Teck with information on the effectiveness of dust emissions control and reduction efforts. Data collected for regulatory purposes are intended to provide Alaska DEC with the necessary information to verify that conditions are protective of human health and the environment.

The soil monitoring and marine sediment monitoring programs (described in the section below regarding the summary of monitoring results) are intended to satisfy a number of requirements, including the regulatory requirements under DEC Contaminated Sites Program, pursuant to 18 AAC 75.360. These two monitoring programs are intended to provide DEC with a means to continue oversight and implement enforcement actions as needed. As such, the results of these programs are formally documented in separate reports to DEC after each monitoring event. Sediment monitoring occurs once every two years, and soil monitoring occurs once every three years. The next sediment sampling event is scheduled for 2022, and the next soil sampling event is scheduled for 2023.

Report Organization

The annual report summarizes work that was conducted during the 2021 calendar year related to each of the implementation plans that are part of the overall RMP. Sections that follow document the communication, dust emissions reduction, remediation, worker dust protection, uncertainty reduction, and monitoring actions taken in 2021.

Risk Management Actions Taken in 2021

The following sections of this annual report summarize each implementation plan, the corresponding risk management objectives, and the actions taken during the 2021 calendar year toward achieving these objectives.

Communication Actions

The Communication Plan follows from RMP Objective #6: *Improve collaboration and communication among all stakeholders to increase the level of awareness and understanding of fugitive dust issues*. To achieve this objective, the Communication Plan was developed with the goal: "To establish consistent methods for communication and collaboration among stakeholders regarding efforts related to dust emission issues." The plan identified multiple types of communication actions, within three categories: communication, collaboration, and education and outreach. A number of methods from these three categories have been implemented as part of the various risk management programs within the RMP.

The following sections outline actions that were taken in 2021 by the Red Dog Environmental and Communication Relations Department to increase communication and participation between RDO and the communities, and to ensure that information is being communicated to all stakeholders and interested parties in an effective manner:

Community Meetings

Community meetings typically provide the opportunity for Red Dog to give the communities updated information on operations, to learn from attendees, discuss concerns, and to discover what questions community members have about Red Dog. In 2021, these meetings were conducted virtually. Below are examples of meetings and events that occurred in 2021:

- Exploration engagement meetings with the Kivalina IRA, Noatak IRA, and Red Dog Subsistence Committee
- Joint Leadership meetings with the Kivalina IRA, Kivalina City Council, and Noatak IRA Council

- Water discharge management engagement meetings with Kivalina IRA, Kivalina City Council, and Noatak IRA Council
- Multiple meetings with the Siñġagmiut Working Group (The Working Group was formed to address environmental concerns, human health issues, traditional land use, and other topics decided on by the Kivalina representatives. To date, topics have focused on water quality testing in the community, tailings dam information sharing, human health studies and employment.)
- Eight helicopter overflights to monitor pre-discharge and post-discharge conditions for Kivalina residents
- Nine Village Fuel Program fuel transfers with the community of Noatak
- 2021 Kivalina Whaling Captains Gas Donation (where 10 whaling captains received two drums of gas each)
- 2021 Marine Mammal Hunter Gas Donation (where 11 Noatak hunters received two drums of gas each)
- Five meetings with Selawik and DEC in response to Selawik Oil Spill
- Eight meetings with the Northwest Arctic Borough School District Youth Leaders program
- Two Red Dog Community Engagement meetings with NANA
- Village Improvement Commission meetings
- Northwest Arctic Borough and Assembly Meetings
- One Annual Hunters meeting in Kivalina
- Nine Village Fuel Program fuel transfers with the community of Noatak
- Four NANA and Teck Community Engagement meetings
- Six Community Wellness Taskforce work sessions where updates were delivered on regional wellness progress at Regional Elders Council meetings
- Caribou Hunter Success Working Group Meeting

- Forty-two contributions for a total of $702,777 for the year, including $19,930 in-kind contributions and $150,000 dedicated specifically to COVID-19 relief funds. Examples of contributions are as follows:
    - Access to food
    - Heating fuel and utilities
    - Quarantine and testing expenses
    - Capacity support for testing locations
    - Kobuk 440 supporting wellness through Inupiaq tradition
    - Emergency safe drinking water—Ambler
    - Emergency fuel spill response—Selawik
    - Emergency response to flooding—Buckland
    - Community funeral support
    - Community spring cleanup
    - Community 4th of July activities
    - Regional back to school activities
    - Noatak Student Activities Fund
    - Iron Dog Hospitality House
    - USMC Toys for Tots at Christmas
    - Thanksgiving and Christmas community events
    - Noatak Hasty Crew emergency response equipment
    - Aqqaluk Trust Youth Leadership Development Social Media Outreach

Subsistence Committee Meetings

The Red Dog/NANA Subsistence Committee is an advisory committee made up of hunters and Elders from Noatak and Kivalina. The committee shares traditional knowledge with Red Dog Mine operators and discusses possible effects of mine operations on subsistence activities. Red Dog holds quarterly meetings with the Subsistence Committee. This provides a key opportunity to obtain input from traditional ecological knowledge holders and Elders.

In 2021, discussions were centered around the following:

- Past Spill Site Reclamation—Reclamation at historical spill sites (previously cleaned up to DEC Standards) was discussed with the Subsistence Committee. A review of the RDTWG meeting that occurred in July 2021 was provided. RDO has voluntarily updated the Tundra Treatment Guidelines document and presented the tracked changes to the DEC, to reflect how climate change may be changing best management practices for reclamation in the Northwest Arctic.

- Port CSB Building Roof Residing—Panels on the CSB #1 roof and walls at the port are going to be replaced. The Subsistence Committee previously selected gray as the color. All old metal panels were washed, and sent offsite to a scrap metal recycler.
- Marine Mammal Harvest—RDO voluntarily delays all shipping season activities and vessels from approaching the port in early spring until the Subsistence Committee meets with RDO and gives permission to bring in vessels for the summer port activities, including the shipping. The goal is to minimize potential impacts to the local community's subsistence hunting activities for marine mammals, including beluga, walrus, and Ugruk (bearded seal). Multiple meetings were conducted leading up to the start of the shipping season to ensure that all parties were communicating about the location and status of beluga, walrus, and Ugruk hunting activities. In 2021, the voluntary delay was the longest ever recorded in RDO history, and the Subsistence Committee mentioned its appreciation for the care RDO provided with regard to subsistence hunting.

Dust Emissions Reduction Actions

The Dust Emissions Reduction Plan is intended to achieve RMP Objective #1: *Continue reducing fugitive metals emissions and dust emissions*. In order to achieve this objective, the Dust Emissions Reduction Plan was developed with the goal: "To reduce the amount of fugitive dust released into the environment near the DMTS and Red Dog Mine to protect human health and the environment."

Road Dust Emissions Reduction Actions

During the warmer months when snow and ice are no longer present, calcium chloride is applied to the gravel roads as a dust suppressant because it retains moisture for prolonged periods. In addition, water trucks spread water on the port and mine site roads. Using the calcium chloride with water applications holds down dust and stabilizes unpaved road surfaces.

Tailings Beach Dust Suppression

In 2021, an ice cap was built over the tailings beach for dust suppression for the first time, to trial ice as a new method of dust suppression. Tuuq Drilling, LLC (Tuuq) was contracted to

complete dust suppression application on the Tailings Beaches. Tuuq applied 74,000 gallons of water to the tailings beach surface using a Terramac 9T Crawler (Terramac) from October 18 to October 21, 2021. The Terramac has a 2,000-gallon tank, which was filled using a water truck. The 3-inch pump, located at the rear, is attached to a sprayer nozzle that is used to apply water for creating an ice cap on the tailings. The sprayer nozzle creates a ~25-ft fan of water directly behind the Terramac. The Terramac continued to apply water in this manner until it was 100 ft away from open water/ice or until the tailings were deemed too saturated to safely traverse. To safely apply water within the non-trafficable area, the nozzle was directed 90 degrees to the Terramac's travel direction during the last pass on the tailings beach.

Dust suppression application occurred on the Wing Wall Tailings Beach on October 22, 2021, in a different manner, because the tailings were too soft and therefore the Terramac was unable to travel directly on the tailings. Therefore, Tuuq applied 36,000 gallons of water to the tailings surface using a Terramac and a sprinkler system. The 3-inch pump on the Terramac was attached to a sprinkler to apply water from the wing wall crest. The sprinkler created a ~50-ft fan of water in a semi-circle from the upstream crest. Once an area was sufficiently covered with water, the sprinkler was manually moved along the crest and the Terramac would drive to the next location. This method was utilized because the tailings in that area were too saturated for the Terramac to safely travel.

Year-Round Air Wash

In 2021, the “waterless” truck wash at the port Truck Unloading Building (TUB) continued to be used. The air wash uses high-powered blowers to remove residual dust from the trucks following loading and before exiting the TUB. The system designed for the TUB consists of six high-powered air blowers that are typically used to dry cars in automatic car washes.

Mine Area Dust Emissions Reduction Projects

A dust suppression product trial for HAULAGE-DC™ was considered for 2021, but safety concerns (potential truck slippage) put the trial on hold.

Remediation Actions

The Remediation Plan is intended to facilitate the achievement of RMP Objective #2: *Continue remediation or reclamation of selected areas to reduce human and ecological exposure.* To achieve this objective, the remediation plan was developed with the goal: “To define a consistent method for identifying and selecting affected areas and implementing remediation and/or reclamation.” Specific requirements for remediation are set forth in various permits and approved documents such as the Red Dog Reclamation and Closure Plan.

Harvesting Seeds for Red Dog Reclamation Projects

Since 2015, Teck and NANA have invested in training, seed harvests, and seed testing, to support development of local native seed market in the NANA Region to sell seed to Teck to revegetate disturbed lands at the mine. Through 2019, seed harvest training was offered in Noatak, resulting in a group of trained harvesters who consistently produced high quality pure, live seed from several local native forbs (herbaceous flowering plants). The COVID pandemic prohibited supervised harvests in Noatak in 2020 and 2021, and despite multi-year efforts by Teck to support seed harvest, no independent harvests have been conducted to date.

As part of RDO’s biodiversity management plan, and best reclamation practices, locally adapted native seed is highly desirable to maintain biodiversity in reclamation projects, and to yield successful revegetation of disturbed lands. Seeds from herbaceous flowering plants (referred to as forbs) are a valuable component of reclamation projects. Locally adapted forbs, specifically

those grown near sites that require reclamation, are preferred. Described below is a synopsis of multiple efforts made by Teck in 2021 to acquire seeds for upcoming reclamation projects along the road, and at material sites.

Noatak Seed Harvest Program

Teck and NANA began the Noatak Seed Harvest Program in 2015 to procure locally sourced native species to revegetate areas slated for reclamation at Red Dog Mine. In 2021, due to COVID-19, travel to Noatak was restricted or prohibited and therefore no in-person outreach was conducted; instead, seed procurement outreach activities were limited to the following:

- Phone calls to previously trained harvesters
- The Noatak Announcements Facebook Group
- Posting of paper posters in the community.

Despite these efforts, no seed was collected in Noatak in 2021.

Red Dog Seed Harvest Program

Due to COVID-19, the Noatak Seed Harvest Program did not occur in 2020 or 2021. Instead, 2021 seed harvest was instead focused at RDO along the DMTS road, as a continuation of 2020 activities. In 2021, NANA-owned and State-owned lands were evaluated for potential harvest species. Based on 2020 observations, it was inferred that mid-July would yield a higher abundance of seed than in the prior year. Unfortunately, in 2021, heavy rains and winds may have contributed to limited availability of seed as most seed had already cast. Tussock cottongrass (*Eriophorum vaginatum*) was harvested from the area surrounding the Gas Exploration sites, and frigid sweet coltsfoot (*Petasites frigidus*) was harvested in the vicinity of DMTS Mile Post 3. The Alaska Plant Materials Center (PMC) cleaned and tested all seed harvested in 2021, to yield a total of 20.7 grams of pure live *E. vaginatum* seed and 2.1 grams of pure live *P. frigidus* seed. The goal was to identify and harvest seed to revegetate spill sites along the DMTS.

Kivalina Native Seed Reconnaissance Study

Past conversations with Kivalina residents indicated there might be interest in creating a Kivalina Seed Collection Program, similar to what was developed in Noatak. Teck was interested in knowing if conveniently located potential seed harvest areas were present in the vicinity of Kivalina. Teck hired f&t in July 2021 to do some visual observations and reconnaissance along the lower Wulik River, at the K-Hill material site, and along the evacuation route to the new school site. Lands along the evacuation route consisted largely of wetlands and ponds, and potential cottongrass harvest areas were noted. Additional opportunistic observations were made in August 2021 at the K-Hill material site, and more reconnaissance is planned for 2022.

Ambler Native Seed Reconnaissance Study

In 2021, Onion Portage Adventures (OPA), a local and licensed business that is currently developing a berry harvest and sales business in Ambler, Alaska, expressed interest in selling seed to Teck. Teck supported a seed reconnaissance study in Ambler in 2021 to identify potential harvest species and train OPA to harvest seed. OPA provided local transportation, room and board, and a field crew to support the Study. The study was conducted August 9–11, 2022. The goals of the study were as follows:

- Train OPA to identify forbs and grasses suitable for revegetation at Red Dog Mine ("target species") and evaluate seed maturity.
- Identify populations of target species available in harvest quantities.
- Document the growth phase (phenology) of one or more non-target flowering plants.
- Provide OPA with information to determine if seed harvest is viable and consistent with its business model.
- Potentially harvest one or more target species to evaluate purity, germination, and yield seed for revegetation at Red Dog Mine.

To ensure seeds were harvested from plants in a sustainable manner, no more than one of every three stems was harvested in each stand, or approximately 30% of the total seed heads

present. Kituq Williams and Breanna Sheldon of OPA were a vital part of the field crew and provided subsistence knowledge and, if known, Inupiaq names for local plants at the allotments. In addition, Helena Jones and Lula Sheldon, two Inupiat elders from the Ambler community, were interviewed for their traditional knowledge on potential subsistence uses of the target plants identified in the field.

The PMC cleaned the seed and performed purity and standard germination tests on each species ("AOSA Rules for Testing Seeds," Method 20-30C (Association of Official Seed Analysts, 2016). A few species were identified that OPA could harvest and, after proper cleaning and testing at the Alaska PMC, sell to Teck.

The study was conducted on a total of 11 Native allotments in the village of Ambler and on the Ambler and Kobuk rivers to identify native forbs and locate potential harvest sites. One of the land allotments has already been cleared and leveled, and if non-native species are fully eradicated, the plot may provide suitable farming conditions for local seed. No NANA lands were accessed, crossed, or evaluated during this study.

Native Seed Harvest Booklets

Seed harvesting in the region will continue to be a critical component of reclamation success at RDO. Collection of local native forbs and grasses that are adapted to local habitat will reduce the potential introduction of non-native invasive plant species potentially found in commercial seed supplies. To assist with future plant collections, three separate field guides with photographs and information on desirable reclamation plants in Ambler, in Noatak, and at RDO. The pocket booklets were created in 2021 and also include information on traditional uses, traditional names, and photographs of each species.

Non-Resident Plant Species

In summer 2020, RDO removed commercial grass cultivars that were previously used to revegetate historical spill sites (MP-13.2 and MP-35.4). The grasses had created a thick layer of plant material that seemed to prevent colonization of the area by other tundra plants. The cleared areas were backfilled in 2020. In summer 2021, RDO conducted visual evaluations at the following mile posts along the DMTS: MP-3.1, MP-10.5, MP-13.2, MP-26, MP-27, MP-28.2,

MP-34, MP-35.4, MP-48.5, and MP-48.6. The evaluation consisted of visually observing the excavated areas within spill site boundaries, and within an approximately 30-m radius from the excavation limit into the undisturbed vegetation surrounding the spill site to document presence of non-resident plant species that may have migrated outside the previously revegetated areas. No non-resident species were identified at or in the immediate vicinity of the spill sites in 2021.

Red Dog Tundra Working Group

The RDTWG was established in 2019 to invite agencies and communities to discuss best management practices related to coordinating cleanup activities and rehabilitating spill sites along the DMTS. Representatives from the following are involved in the RDTWG: NPS, U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers, Alaska Department of Natural Resources (DNR), U.S. Coast Guard, Northern Alaska Environmental Center, Kivalina City Council, Kivalina IRA, NANA, NANA/Lynden, and Alaska Industrial Development and Export Authority.

The RDTWG met in July 2021 at RDO; the meeting included a tour to visit several historical spill sites that were previously cleaned up according to DEC guidelines using excavators to remove concentrate from the tundra. RDTWG members present were Oral Kuki Hawley (Kivalina IRA), Theodore Booth (Kivalina IRA), Kimberley Maher (DEC-SPAR), Alyssa Millard (DNR), and Peter Neitlich (NPS), and Sue Bishop and Tim Cater (ABR Restoration Ecologists). Cleanup levels had been achieved at these sites, and instead the focus of the meeting was to design a rehabilitation study to learn more about tundra rehabilitation methods in the northwest Arctic.

The rehabilitation study was proposed to learn more about tundra rehabilitation following land disturbance in the northwest Arctic. The goal of the study is to identify the most effective and efficient rehabilitation techniques for concentrate spill sites along the DMTS road. With the exception of one diesel spill site, the sites selected for the rehabilitation study included locations where historical spills had occurred; note all spill were cleaned up using excavation and meet cleanup standards. The rehabilitation study was designed with input from all members of the RDTWG present at the July 2021 meeting. The study will examine revegetation success following treatments at three types of sites: 1) excavated and unvegetated spill sites with seed and fertilizer treatments; 2) minimally excavated spill sites with the surrounding tundra treated

with fertilizer; and 3) previously rehabilitated sites using either seed and fertilizer or tundra sod. The rehabilitation study will also include ongoing monitoring on historical spill sites that have been successfully reclaimed, as these sites may improve our understanding of the rehabilitation process over long periods.

Concentrate Spills in 2021

There were no concentrate spills along the DMTS in 2021.

Worker Dust Protection Actions

The Worker Dust Protection Plan was prepared in response to RMP Objective #7: *Protect worker health*. To achieve this objective, the Worker Dust Protection Plan was developed with the goal: "To minimize worker exposure to fugitive dust, provide ongoing monitoring of exposure, and ensure a comprehensive communication system."

Safety is a core value for Teck, and the company is committed to providing leadership and resources for managing safety and health. Accordingly, the company has developed Environment, Health, Safety and Community Management Standards applicable to its operations worldwide. In addition, Teck has a comprehensive Occupational Safety and Health Program tailored specifically to RDO to protect worker health. The program complements the corporate standards and is designed to manage all aspects of workplace safety and health, including worker dust protection. The Worker Dust Protection Plan ties in closely with the existing health and safety programs at the mine that are overseen by the Red Dog medics.

The Blood Lead Biological Monitoring Program is for personnel who work in areas that meet or exceed Occupational Safety and Health Administration action levels for lead exposure. The frequency of monitoring for an individual worker is dependent on previous blood lead level history. The higher an individual's blood lead levels, the more frequent that worker will be monitored. The overall goal is to keep worker lead exposure as low as possible through engineering controls, administrative controls, and use of personal protective equipment and proper hygiene practices.

Worksite blood lead monitoring was conducted in 2021 by the Red Dog Human Resources Medical Department. Blood lead level testing is performed for all employees on a regular basis.

The Red Dog blood lead standards are as follows:

- 0–20 mcg/dL: continue testing employee every 6 months
- 20.1–25 mcg/dL: test employee every 3 months and review protocol for use and cleaning of respirator
- 25.1–40 mcg/dL: continue testing employee every month and provide employee counseling by supervisors on the importance of proper respirator usage and the need for best practices regarding personal hygiene
- >40 mcg/dL: relocate employee from normal work area to an area with lower lead exposure until blood lead levels are 25 mcg/dL or less.

In 2021, all female employees had blood lead levels below 15 mcg/dL. In 2021, seven males had blood lead levels in the 20–24 mcg/dL range, and one male had blood lead levels in the 35–39 mcg/dL range. For these individual cases, the supervisor discussed elevated lead levels and reviewed work habits with the employee, including cleaning of filter mask, appropriate filter change protocols, and personal hygiene habits. No Teck Red Dog workers were removed from the job due to elevated blood lead levels.

Uncertainty Reduction Actions

The Uncertainty Reduction Plan follows from RMP Objective #5: *Conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment*. To achieve this objective, the Uncertainty Reduction Plan was developed with the goal: "To identify and prioritize prospective research or studies to reduce uncertainties in the assessment of effects of fugitive dust to humans and the environment." In 2020, the white paper titled "*Effect of Time on Bioaccessibility of Aluminum and Barium in Arctic Soils*" was shared as part of the annual report. Comments were provided by DEC. The comments received are shared in Appendix A of this annual report, along with the responses. The review is greatly appreciated.

Monitoring Actions

The Monitoring Plan (Exponent 2014) is intended to achieve the following RMP objectives:

- Objective 1: Continue reducing fugitive metals and dust emissions (This objective is indirectly addressed through monitoring, to verify effectiveness of operational dust control measures.).
- Objective 3: Verify continued safety of caribou, other representative subsistence foods, and water.
- Objective 4: Monitor conditions in various ecological environments and habitats and implement corrective measures when action levels are triggered.
- Objective 6: Improve collaboration and communication among all stakeholders to increase the level of awareness and understanding of fugitive dust issues.

To achieve these objectives, the Monitoring Plan was developed with the goal: "To monitor changes in dust emissions and deposition over time and space, using that information to: 1) assess the effectiveness of operational dust control actions, 2) evaluate the effects of the dust emissions on the environment and on human and ecological exposure, and 3) trigger additional actions where necessary."

Actions included in the Monitoring Plan were developed from priorities identified during development of the RMP, with input from local stakeholders, technical experts, and state and federal regulatory agencies. This section presents the results of the Monitoring Plan actions implemented during 2021. An overview of the components of the monitoring program along with the frequency of monitoring is shown in Figure 2. A map-based illustration of the risk management monitoring program components and monitoring stations and sites is shown in Figure 3.

Monitoring Programs for DEC Oversight

The marine sediment and soil monitoring programs are ongoing and require DEC oversight, and the monitoring results are also used for trend analysis at RDO. Sediment monitoring is conducted every two years, and soil monitoring occurs once every three years. Both soil and sediment monitoring occurred in 2020, and those results were included in the 2020 RMP annual report. The next sediment monitoring event is scheduled for 2022 and the next soil monitoring even is scheduled for summer 2023.

Operational Monitoring

U.S. EPA Method 22—Visible Emissions Evaluation

Visible emissions evaluations (VEEs) were conducted as required for the Title V of the Clean Air Act operating permit at the mine. VEE monitoring occurs at multiple locations within the mine boundary and at the port. Along all unpaved roads, including the DMTS haul road, calcium chloride and/or water is used to control fugitive dust emissions when the road surfaces are not frozen or when the road surfaces do not exhibit visible surface moisture. To verify the effectiveness of these control measures, VEE observations are conducted daily when road surfaces are dry and not frozen. If dust is visibly present for more than 2 minutes on the unpaved road surfaces, additional calcium chloride or water is applied as soon as practicable and VEE monitoring is repeated to verify fugitive emissions are no longer present. All VEE readings that are required under the Title V permit are submitted twice a year to DEC within the Title V Facility Operating Report.

Partisol (Formerly TEOM) Source Monitoring

Historically at Red Dog Mine and Port, monitoring equipment known as tapered element oscillating microbalance (TEOM) instruments have been used to provide real-time total suspended particulate (TSP) information for mine operators at RDO. The instruments have been used since 2002 to monitor air quality at four locations near sources within the mine and port (Figures 3, 4, 5). However, the TEOM monitoring equipment was no longer supported by ThermoScientific, meaning parts and service for the instrumentation could no longer be procured. To provide for a smooth transition, beginning in 2019, Partisol (Model 2025i) instruments were placed in the same location as the TEOMs (Figures 3, 4, 5) to begin collecting data. In 2021, the TEOMs were retired and the Partisol (Model 2025i) instruments were used exclusively to obtain real-time source monitoring data.

Similar to the TEOMs, the Partisol instruments produce real-time measurements of dust in air and collect discrete samples, which are then analyzed to provide airborne metals concentrations. Measurements are reported as TSP, and zinc and lead concentrations are

reported as TSP-Zn and TSP-Pb, respectively. Partisol instruments are operated continuously[3] to measure real-time TSP. Filters are used to collect TSP over 24-hour periods every third day at the mine and every sixth day at the port, and are then analyzed for TSP-Zn and TSP-Pb. The Mine Partisol samplers are located downwind of the pit and crusher at the Personnel Accommodations Complex (PAC), and at the main tailings dam (T-Dam) downwind of the tailings beach, mill, and other facilities (Figure 4). The Port Partisol samplers are located downwind of the CSBs and in the lagoon area downwind of the concentrate conveyor (Figure 5).

Statistical Trend Analysis for Partisol Data. Statistical testing methods were used to evaluate whether the Partisol (spliced together with prior TEOM) data sets exhibit statistically significant temporal trends in metals concentrations. The Seasonal Mann-Kendall trend test is a nonparametric method to investigate temporal trends in time series containing substantial seasonal variability. For this analysis, the real-time data were summarized on a monthly basis. Seasonal trend tests were conducted using monthly means and monthly upper limit 95th percentile concentrations to evaluate both average conditions and measures of the upper limits over the past four years (beginning of 2018 to end of 2021). Results of the statistical trend tests for real-time data (lead and zinc concentrations) in four locations (Mine PAC, Mine T-Dam, Port CSB, and Port Lagoon) are summarized in Table 1.

The calculated monthly averages for TSP-Pb and TSP-Zn concentrations are shown on Figures 6 and 7, respectively, for all four mine and port Partisol/TEOM locations. The concentrations of lead and zinc at the mine area are typically higher than those at the port area (Figures 6 and 7, respectively). At the mine and port, lead and zinc concentrations were typically lowest in summer months (the months with higher humidity and more road watering for dust control), and highest in winter months (the coldest, driest, and lowest humidity months, when road watering is not possible because of freezing conditions).

[3] Occasional system upsets do occur as a result of weather or equipment failure. Partisol readings are monitored frequently so that system upsets are noted and corrected as soon as possible. Missing or unusable data are noted in the raw data files and are not used in statistical trend evaluations.

- **Mine PAC Results.** The Mine PAC results show significant increasing trends in mean and upper limit 95th percentile concentrations for lead and zinc (Figures 6 and 7, Table 1).
- **Mine T-Dam Results.** There was a significant decreasing trend in both mean and upper limit 95th percentile lead and zinc concentrations over the past four years at the Mine T-Dam (Figures 6 and 7, Table 1).
- **Port CSB Results.** There was a significant decreasing trend in both mean and upper limit 95th percentile lead concentrations at the Port CSB over the past four years (Figure 6, Table 1). In contrast, there was a significant increasing trend in both mean and upper limit 95th percentile zinc concentrations over the past four years (Figure 7, Table 1).
- **Port Lagoon Results.** The Port Lagoon Partisol and TEOM results show significant increasing trends in mean and upper limits 95th percentile concentrations for lead and zinc over the past four years (Figures 6 and 7, Table 1).

Real Time Alarm System Monitoring. Real-time SHARP (synchronized hybrid ambient real-time particulate) monitor (ThermoScientific 5030i SHARP) data are used to monitor for high dust events so that mine activities can be modified (where possible) to reduce dust levels. When air quality measurements exceed a warning level or an alarm level, the alarm status is displayed on the Red Dog weather intranet web page to notify personnel within the Mine Operations and Environmental departments to take corrective action. Examples of these corrective actions include applying water on the roads or stockpiles, or shutting down loading operations during windy conditions.

Road Surface Monitoring

Loose fine materials that may be subject to airborne transport are sampled from the road surface at eight locations every two months. From the mine site to the port, the eight-road surface monitoring station locations are:

- Mine CSB (near exit from truck loading portion of CSB)
- The Y (near the back dam, between the CSB and the Airport)

- Airport
- MS-13 (former material site where road crosses the mine boundary)
- MS-9 (material site between the mine and CAKR)
- R-Boundary (northern boundary of CAKR)
- MS-2 (material site just inside the northern boundary of the port)
- Port CSB Track (road near exit from truck unloading building at the port CSBs).

Samples are analyzed onsite using a portable XRF analyzer to determine lead, zinc, and cadmium concentrations within road surface materials. The "Mine CSB" and "The Y" stations (inside the operational mine boundary) generally exhibit higher metals concentrations and are managed so as to reduce tracking of metals toward the port with a traffic plan and truck wash that is operational during warmer months.

During most recent four-year period (2018–2021), statistical analyses indicate lead, zinc, and cadmium concentrations in road fugitive dust samples from the mine, port, and road have either significantly decreased or show no significant trend (Figures 8, 9, and 10; Table 2). When each location is examined separately, the same was true, no significant increases, except directly outside the Mine CSB, where zinc (but not lead or cadmium) concentrations had significantly increased over the past four years (Table 2).

If measured road surface concentrations at stations outside the mine boundary exceed Arctic Zone Industrial Cleanup Levels for lead, zinc, or cadmium (800, 41,100, and 110 mg/kg respectively[4]) for more than two consecutive sampling periods, that road section is to be remediated and resurfaced as described in the Remediation Plan (Exponent 2011). No additional road remediation was required during 2021 because results for stations outside the mine and port boundaries did not exceed the Arctic Zone Industrial Cleanup Levels.

---

[4] Cleanup levels according to 18 AAC 75.341, as revised in 2008 (available on the internet at https://dec.alaska.gov/spar/csp/docs/75mas_art3.pdf). Note that the cadmium and zinc cleanup level would be lower, at 79 and 30,400 mg/kg, if the zone were considered to be the "Under 40-inch Zone" by DEC, which is a function of the definitions at 18 AAC 75.990.

Dustfall Jar Monitoring

Dustfall jars are passive continuous collectors used for measuring dust deposition; samples are collected every two months at all locations. Approximately 86 dustfall stations are located around the mine, port, and DMTS road (Figure 3), as follows:

- At the mine, approximately 34 jars are placed in locations around the facilities.
- Along the DMTS road, 12 dustfall jars are located at three stations, each with four dustfall jars, two on either side of the road. The DMTS road stations are collocated with road surface sampling stations near the port boundary, the CAKR northern boundary, and midway between CAKR and the mine. The dustfall jars are located approximately 100 m from the shoulder of the DMTS, with 100 m between them, oriented parallel to the road.
- At the port, 38 jars are placed roughly in a rectangular grid throughout the area.
- An additional two jars are considered reference stations, one upwind of the road near Evaingiknuk Creek, and another near the Wulik River, to the north of the mine operation.

Statistical Trend Analysis for Dustfall Jar Data. Temporal trends in deposition rates or metals concentrations in dustfall jar data were evaluated using seasonal trend tests conducted with bimonthly mean and 95th percentiles (method same as discussed above in TEOM section).

- **Lead.** No statistically significant trends were identified in lead deposition rates during the most recent four-year monitoring period at the mine, along the DMTS road, or port (Table 3). Also, no statistically significant trends in lead concentrations were detected along the DMTS road or at the port. However, lead concentrations at the mine dustfall stations did significantly increase over the past four years. Time series plots of lead concentrations and dustfall deposition rates are presented in Figures 11 and 12, respectively.
- **Zinc.** No statistically significant trends were identified in zinc deposition rates during the most recent four-year monitoring period at the mine, along the DMTS road, or port (Table 3). At the mine and port, significant increasing trends in zinc concentrations were

detected (Table 3). No significant trends in zinc concentrations were detected along the DMTS road.

- **Total Solids.** No statistically significant trends were identified in total solids deposition rates during the most recent four-year monitoring period at the mine, along the DMTS road, or port (Table 3). For total solids, the deposition rates have been stable with no statistically significant trends identified at any location over the most recent four-year period (Table 3). Time series plots of total solids dustfall rates are presented in Figure 15.

Caribou Tissue Monitoring

Red Dog Mine is located within the normal annual range of the Western Arctic Herd of caribou. Surveys of caribou tissue metals concentrations have been conducted periodically since 1984 by the Alaska Department of Fish and Game and these data provide baseline information against which more current studies may be compared. Previous caribou tissue monitoring events near Red Dog were completed in 2002 and 2009. The next caribou tissue monitoring (meat, kidney, liver) event is currently scheduled for 2025; therefore, there are no results to present for 2021.

Summary of Monitoring Results

Dust monitoring data from the Partisol and TEOM air samplers, road surface samples, and the dustfall jars were statistically evaluated to assess the current trends over the most recent four-year period. A summary of statistical trend analysis results for Partisol and TEOM, road surface, and dustfall jar monitoring programs is presented in Table 4. Table 4 provides an at-a-glance overview of results of dust monitoring programs.

Road dust samples collected at locations at the mine, road, and port have shown either significant decreases or no statistically significant change over the past four-year period for lead, zinc, and cadmium (2018–2021). Dustfall jars along the road and also show no significant changes over the past four-year period for lead and zinc concentrations and in rates of dustfall deposition. The Partisol data collected near the mine tailings dam show significant decreases in lead and zinc concentrations over the past four-year period, but in contrast, the mine Partisol

data shows significant increases for lead and zinc concentrations. Similarly, dustfall jars at the mine indicated significant increases in lead and zinc over the past four years. A summary of all results is shown in Table 4.

The goal of the Red Dog Operations Fugitive Dust Risk Management Program *[Minimize risk to human health and the environment surrounding the DMTS and outside the Red Dog Mine boundary over the life of the mine*] is to ensure that dust levels remain low using the risk management actions discussed in this 2021 report. These monitoring programs provide Red Dog with data at a high frequency (data collection ranging from every other day to once every two months) and within areas located right near the operations. The intent is to use this information to inform Red Dog where the most attention will be needed and to avoid increases beyond the Red Dog Mine and Port ambient air/solid waste permit boundaries. The 2021 results indicate some increases noted over the last four-year period, indicating that additional attention to potential dust controls will need to be considered in 2022.

References

Association of Official Seed Analysts, 2016. AOSA Rules for Testing Seeds, Method 20-30C.

Exponent, 2007. DMTS fugitive dust risk assessment. Prepared for Teck Cominco Alaska Incorporated. November 2007.

Exponent, 2008. RMP Exponent. 2008. Fugitive dust risk management plan. Red Dog Operations, Alaska. Prepared for Teck Cominco Alaska. Draft. August 2008.

Exponent, 2010. Fugitive Dust Risk Management Communication Plan. Prepared for Teck Alaska Incorporated. February 2010.

Exponent, 2011a. Fugitive Dust Risk Management Dust Emissions Reduction Plan. Prepared for Teck Alaska Incorporated. December 2011.

Exponent, 2011b. Fugitive Dust Risk Management Remediation Plan. Prepared for Teck Alaska Incorporated. June 2011.

Exponent, 2011c. Fugitive Dust Risk Management Worker Dust Protection Plan. Prepared for Teck Alaska Incorporated. October 2011.

Exponent, 2012. Fugitive Dust Risk Management Uncertainty Reduction Plan. Prepared for Teck Alaska Incorporated. October 2012.

Exponent, 2014. Fugitive Dust Risk Management Monitoring Plan. Prepared for Teck Alaska Incorporated. May 2014.

Ford, S., and L. Hasselbach, 2001. Heavy metals in mosses and soils on six transects along the Red Dog Mine haul road, Alaska. NPS/AR/NRTR-2001/38. National Park Service, Western Arctic National Parklands.

Teck, 2016. Reclamation and Closure Plan, Red Dog Mine, Alaska, USA. August 2016.

Appendix A

Figures

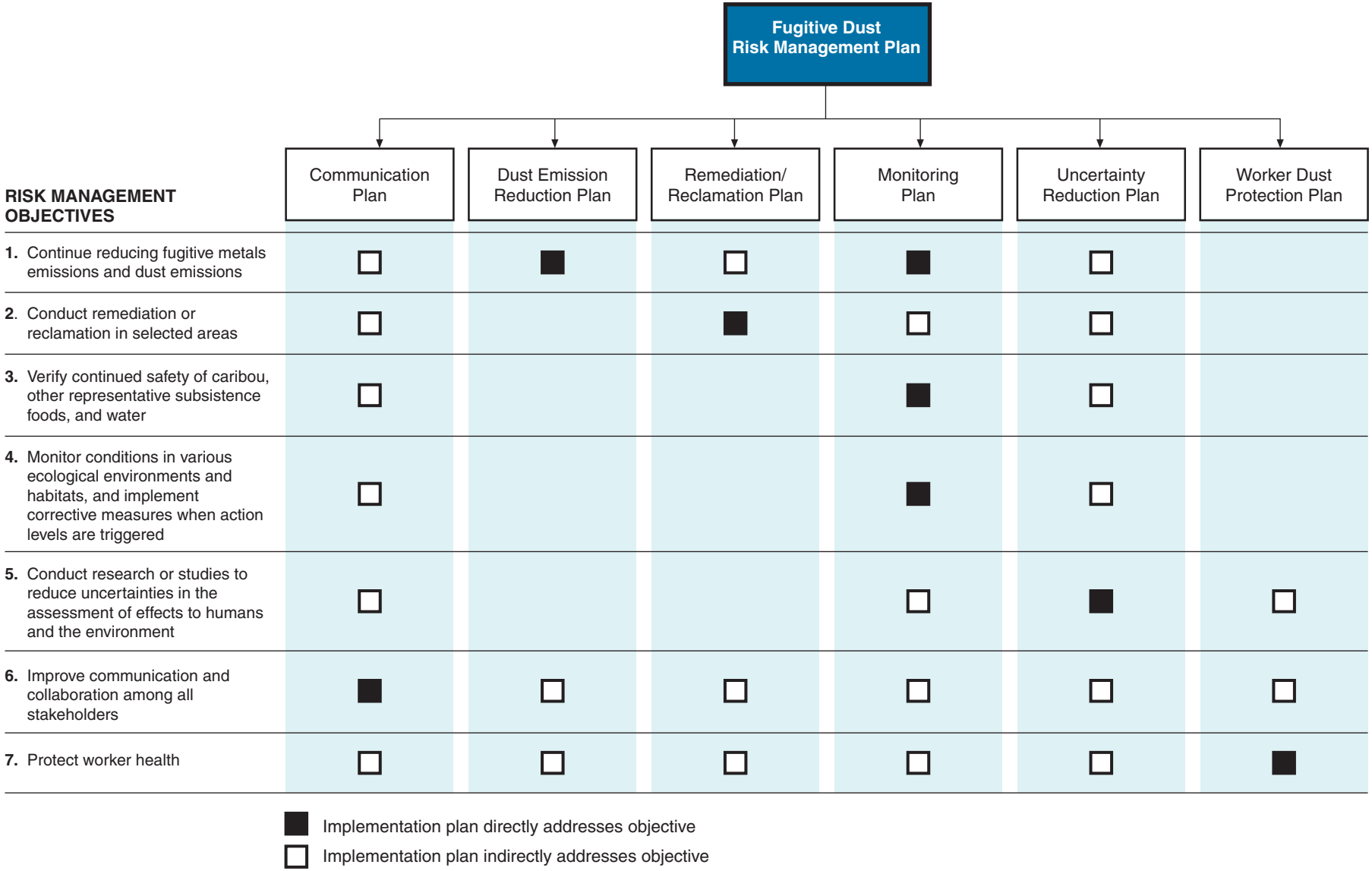

Figure 1. Risk management objectives and associated implementation plans

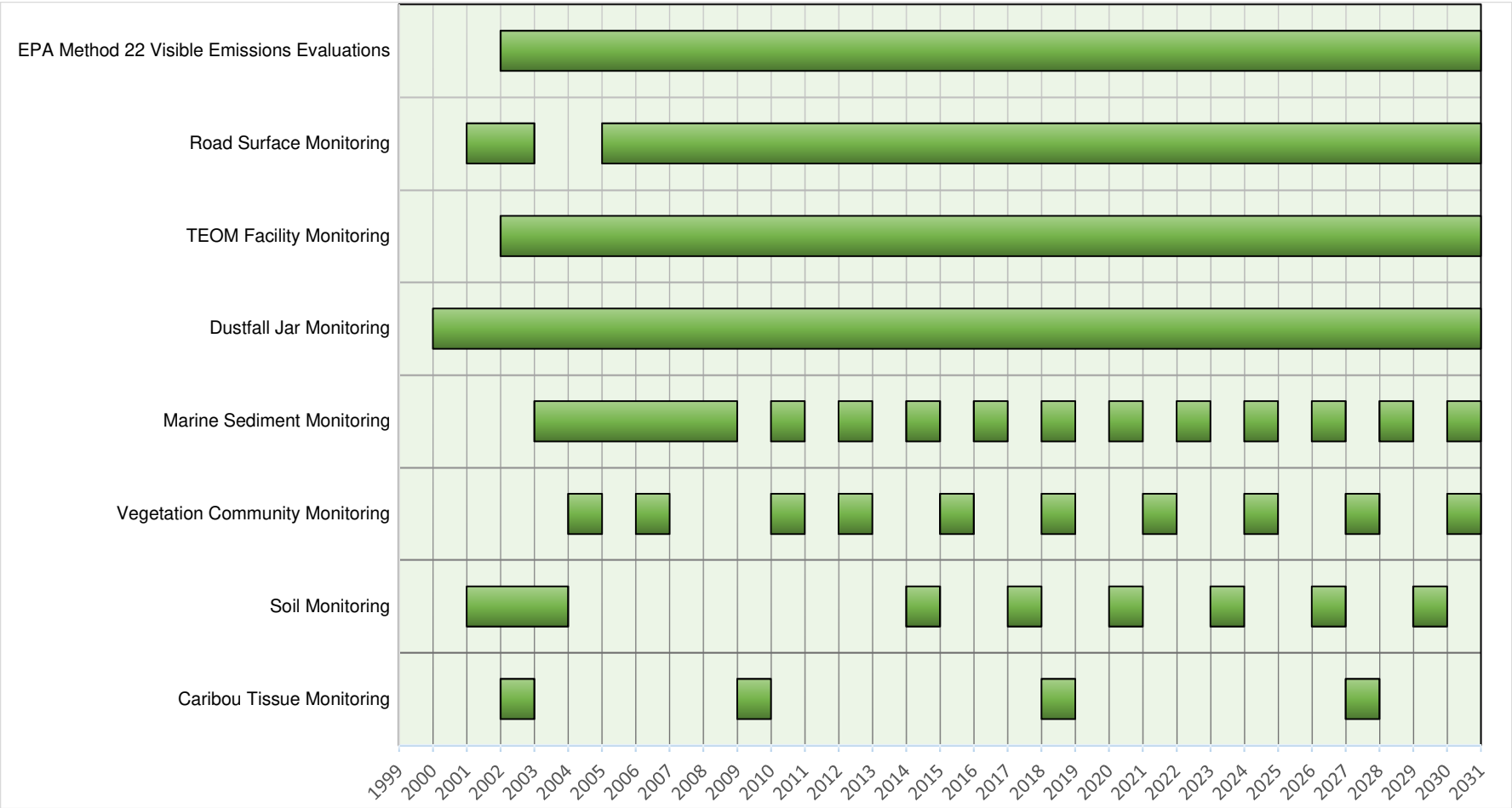

Figure 2. Monitoring timeline with program frequencies

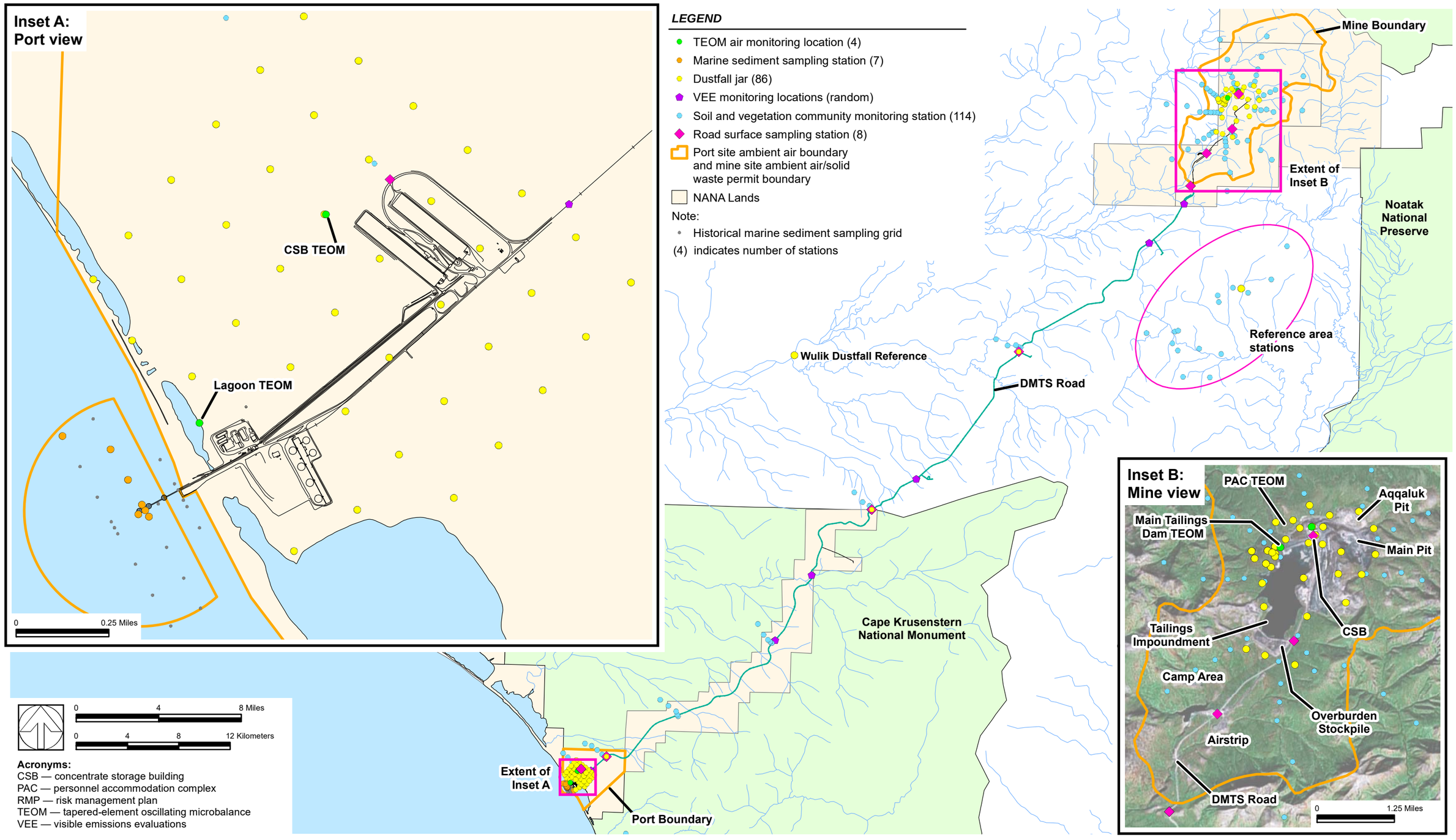

Figure 3. Overview of risk management monitoring programs

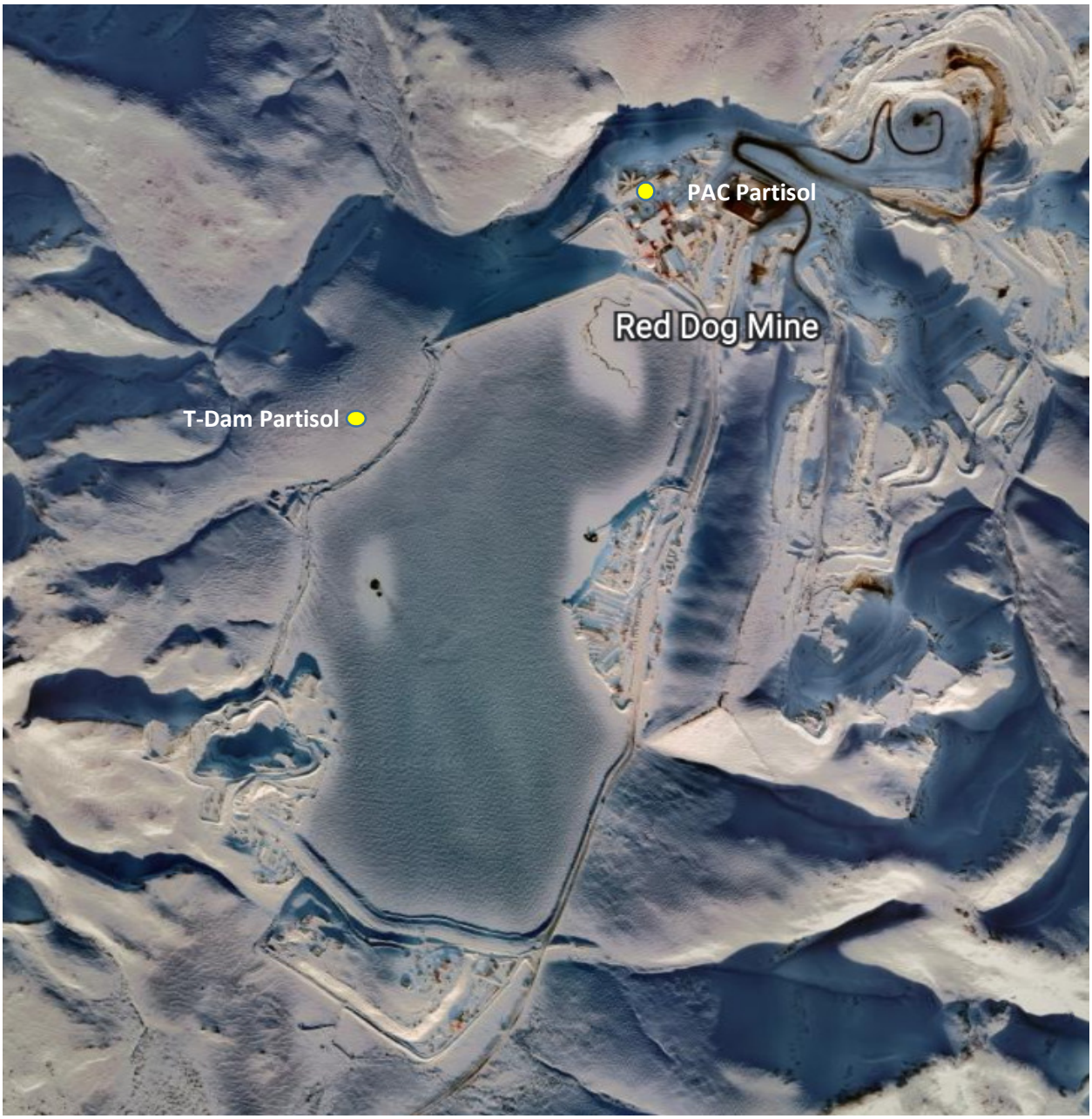

Figure 4. Mine Partisol/TEOM locations

Figure 5. Port Partisol/TEOM locations

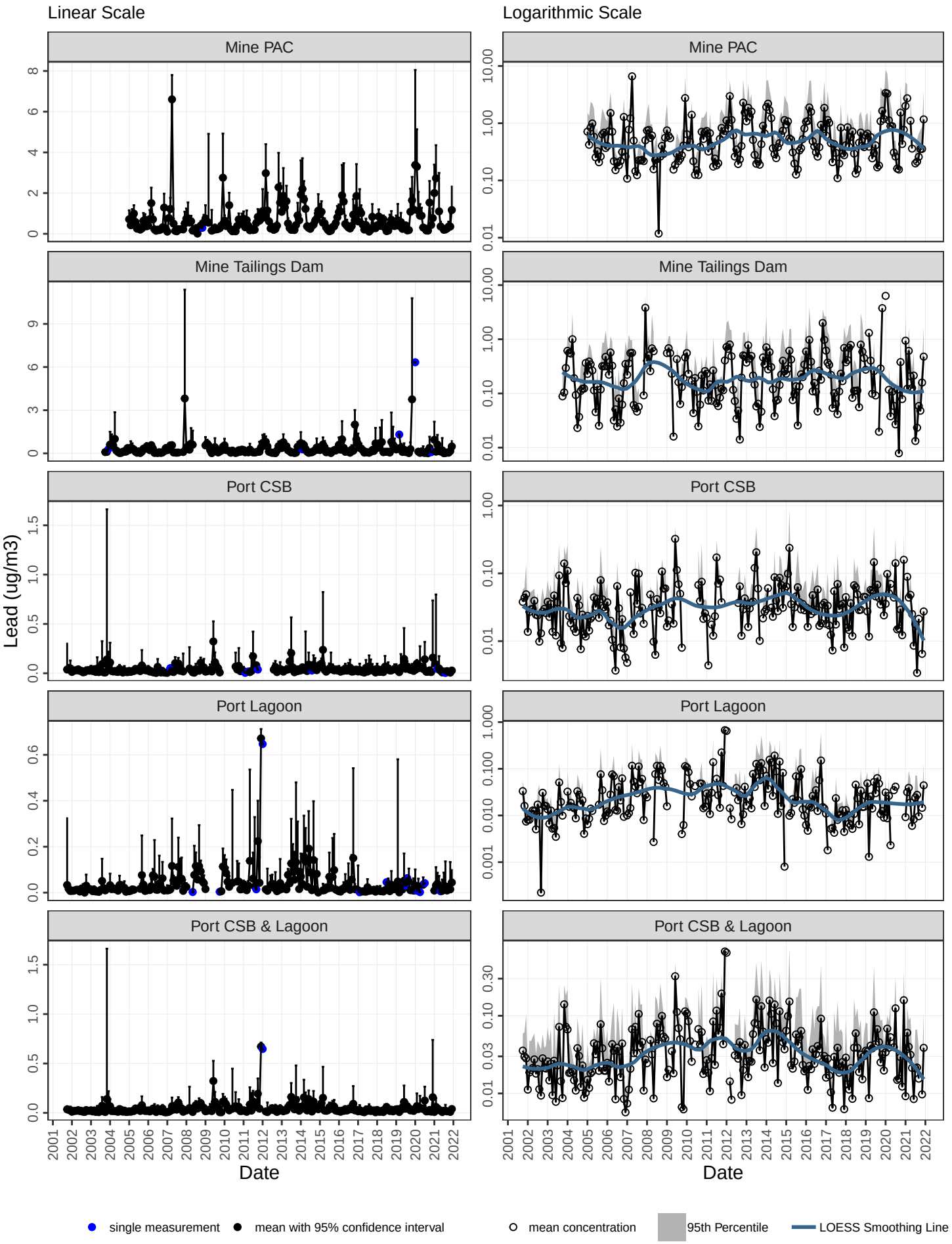

Figure 6. TEOM Lead Concentration plots (all years)

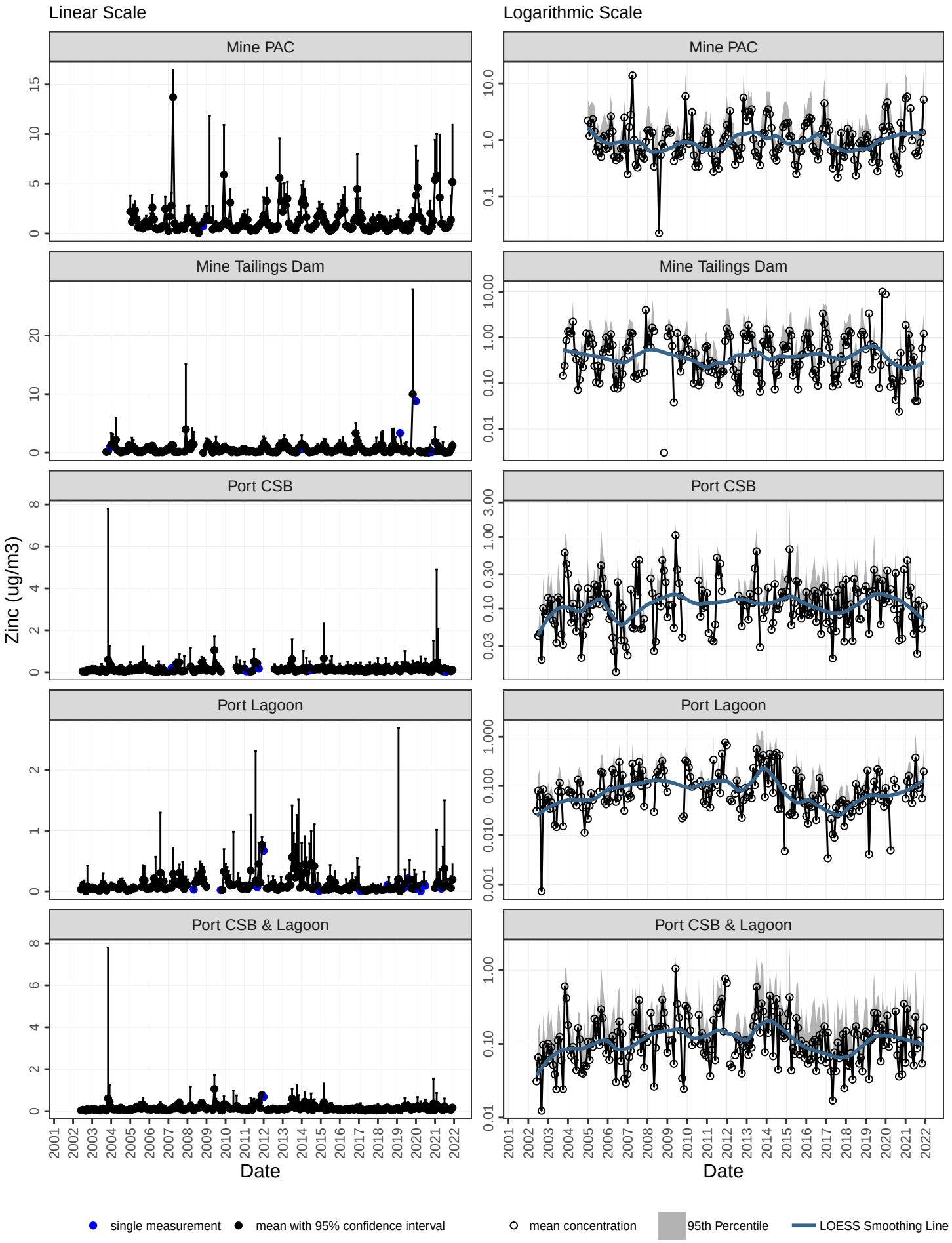

Figure 7. TEOM Zinc Concentration plots (all years)

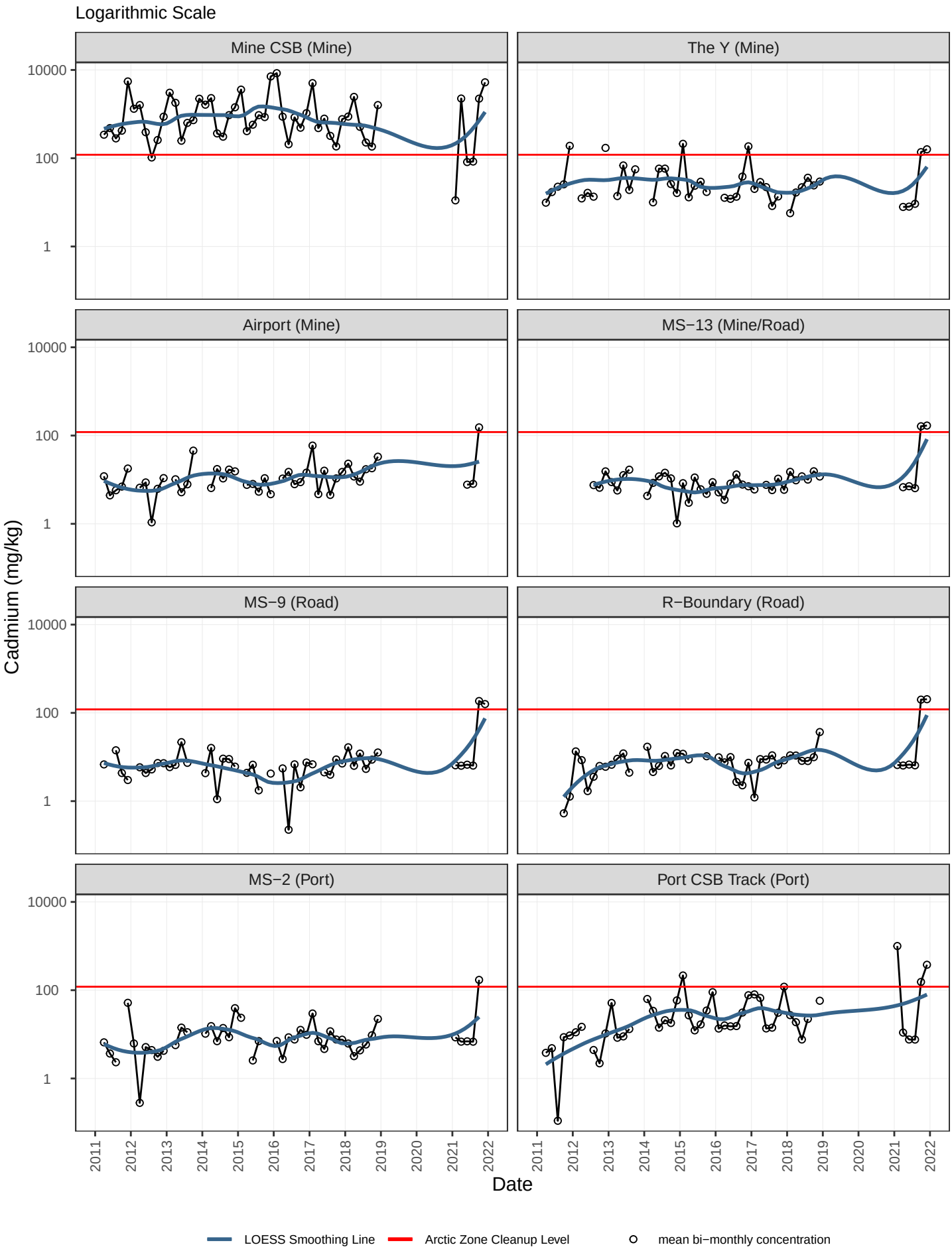

Figure 8. Road Surface Cadmium Concentrations (all years)

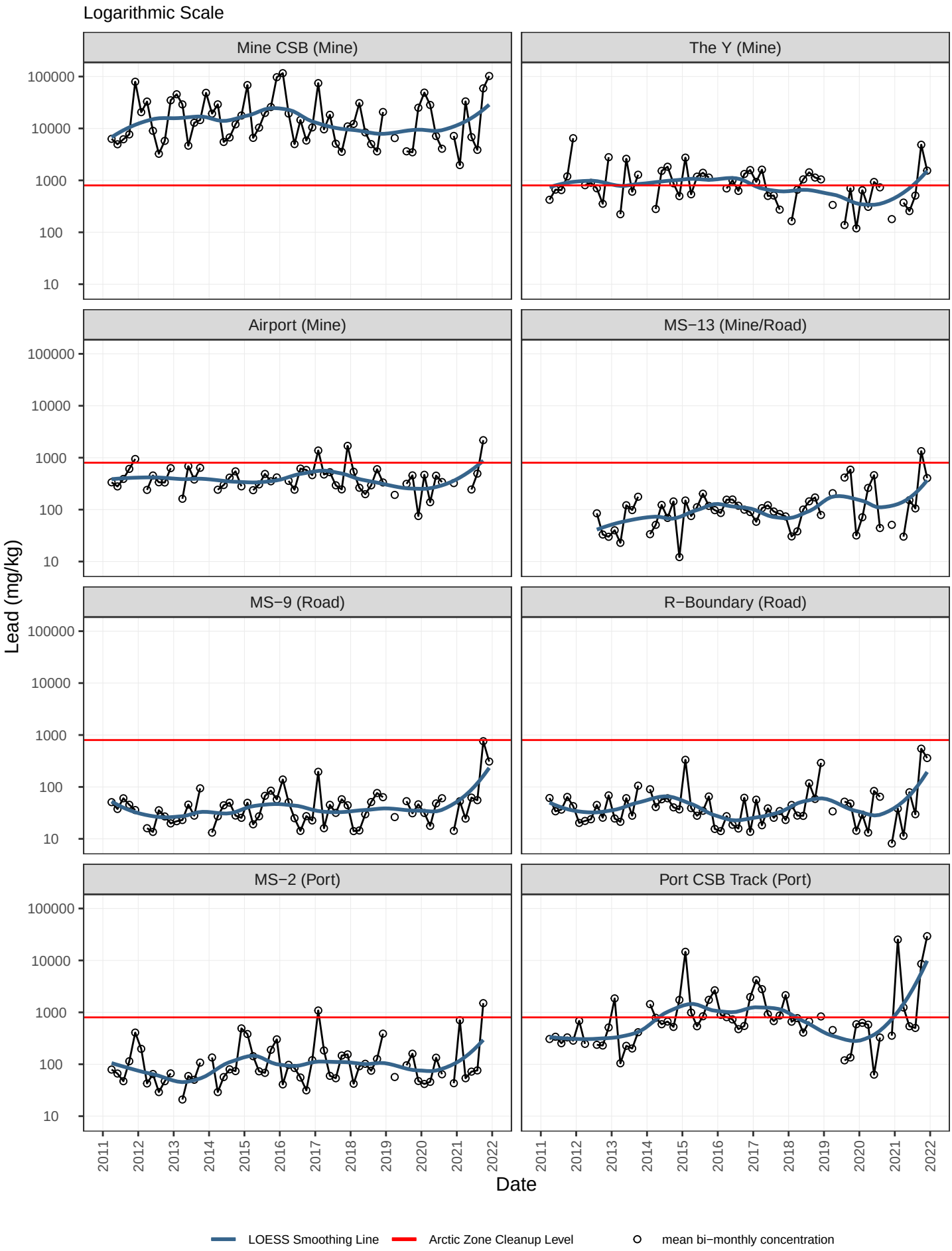

Figure 9. Road Surface Lead Concentrations (all years)

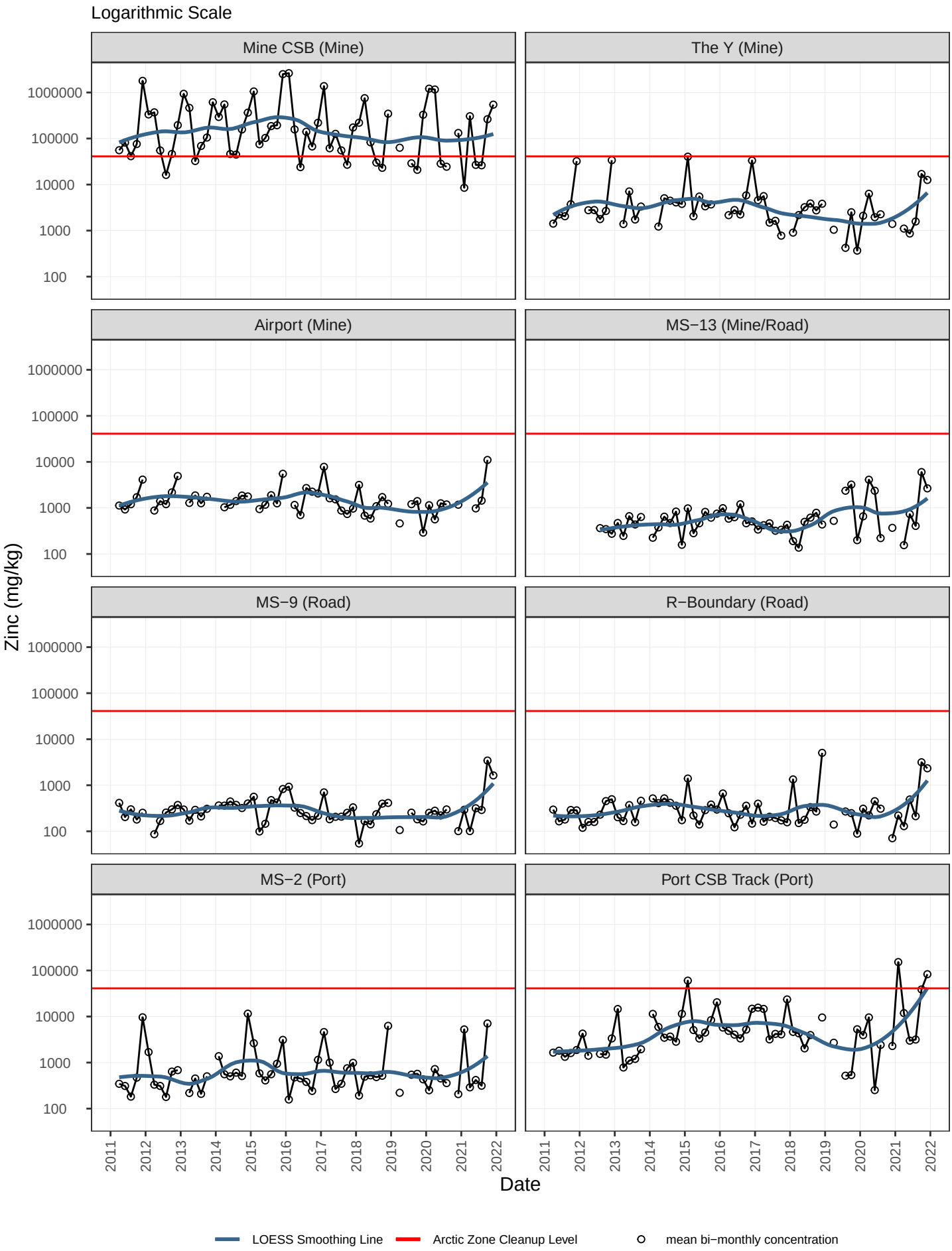

Figure 10. Road Surface Zinc Concentrations (all years)

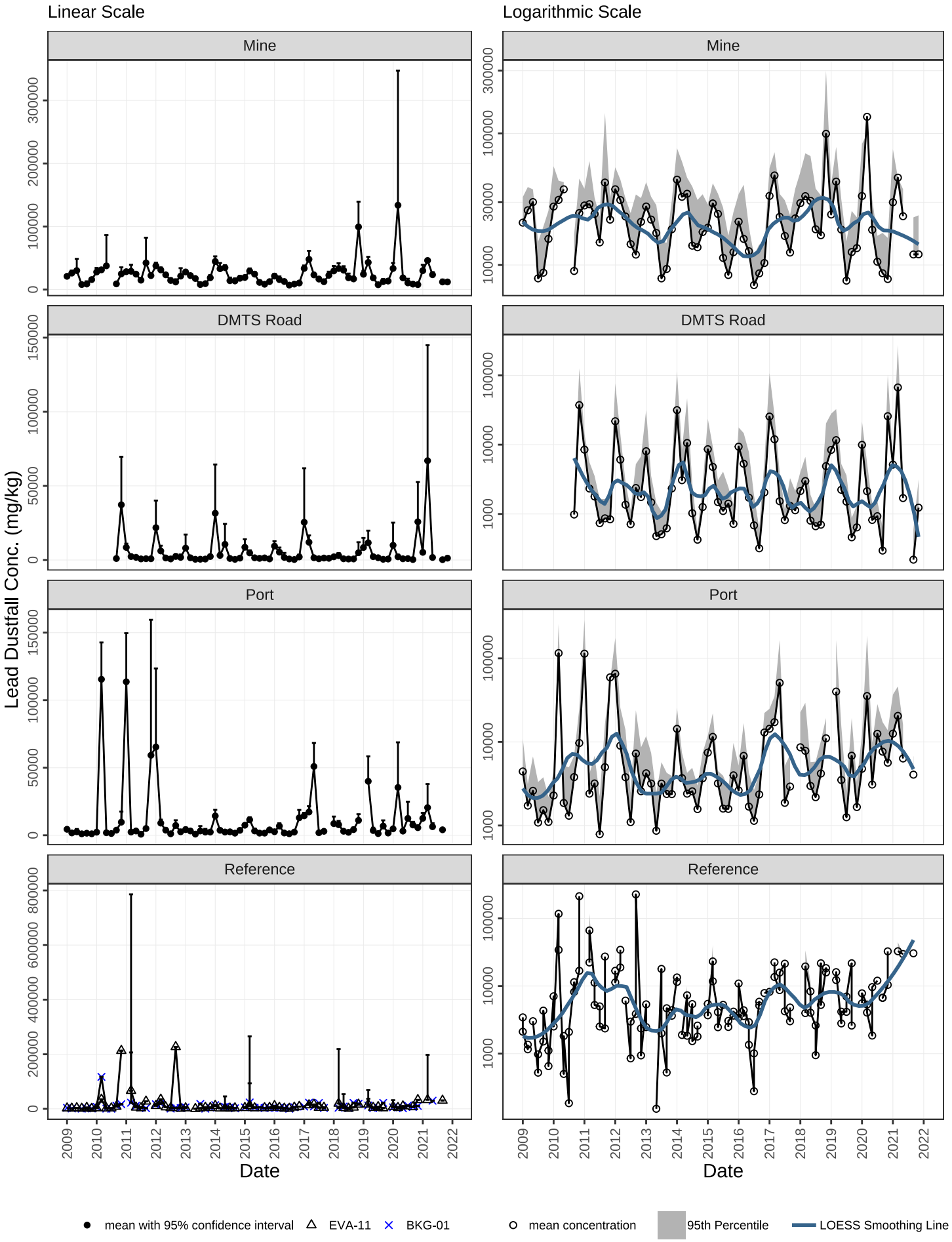

Figure 11. Dustfall Jars Lead Conc. plots (all years)

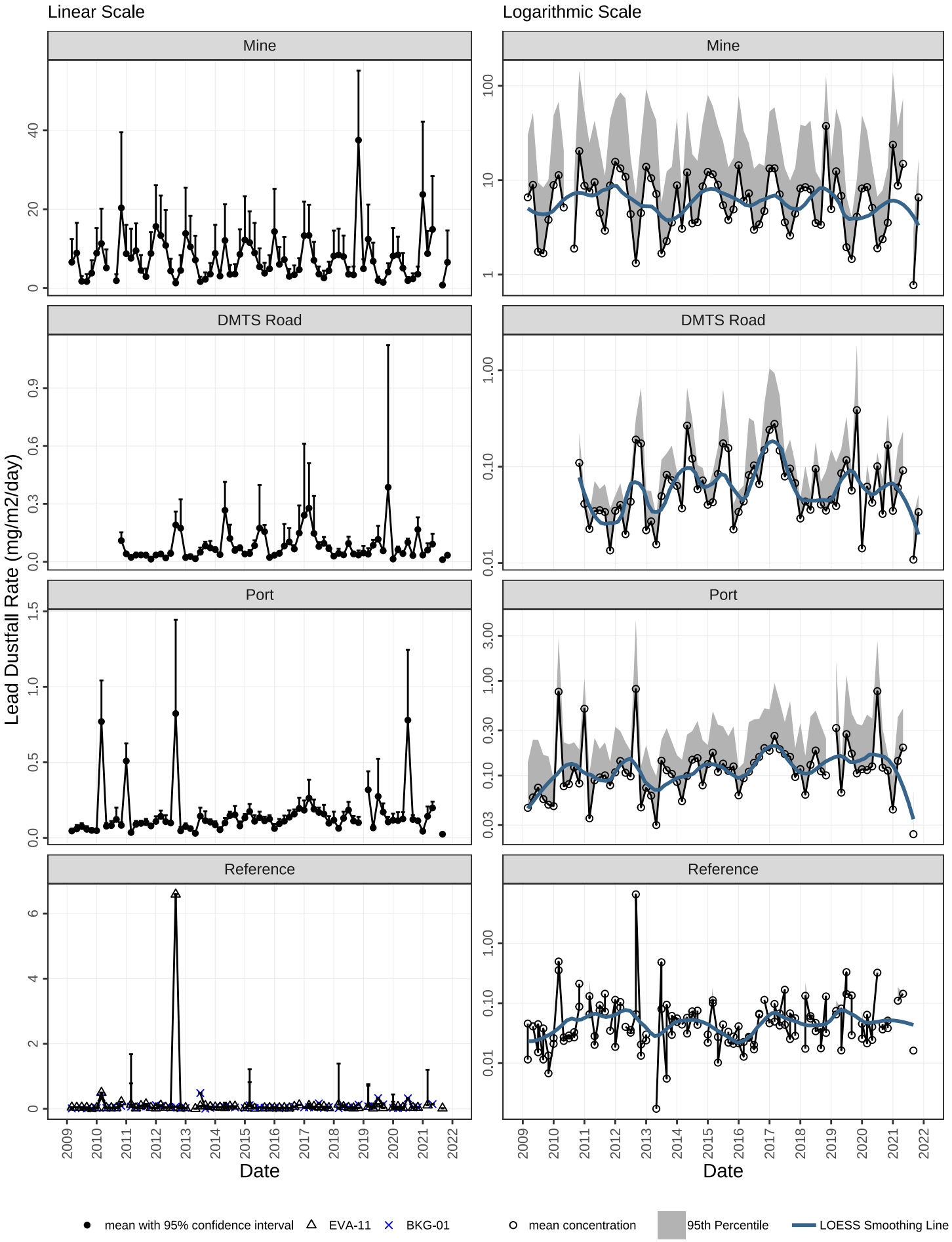

Figure 12. Dustfall Jars Lead Rate plots (all years)

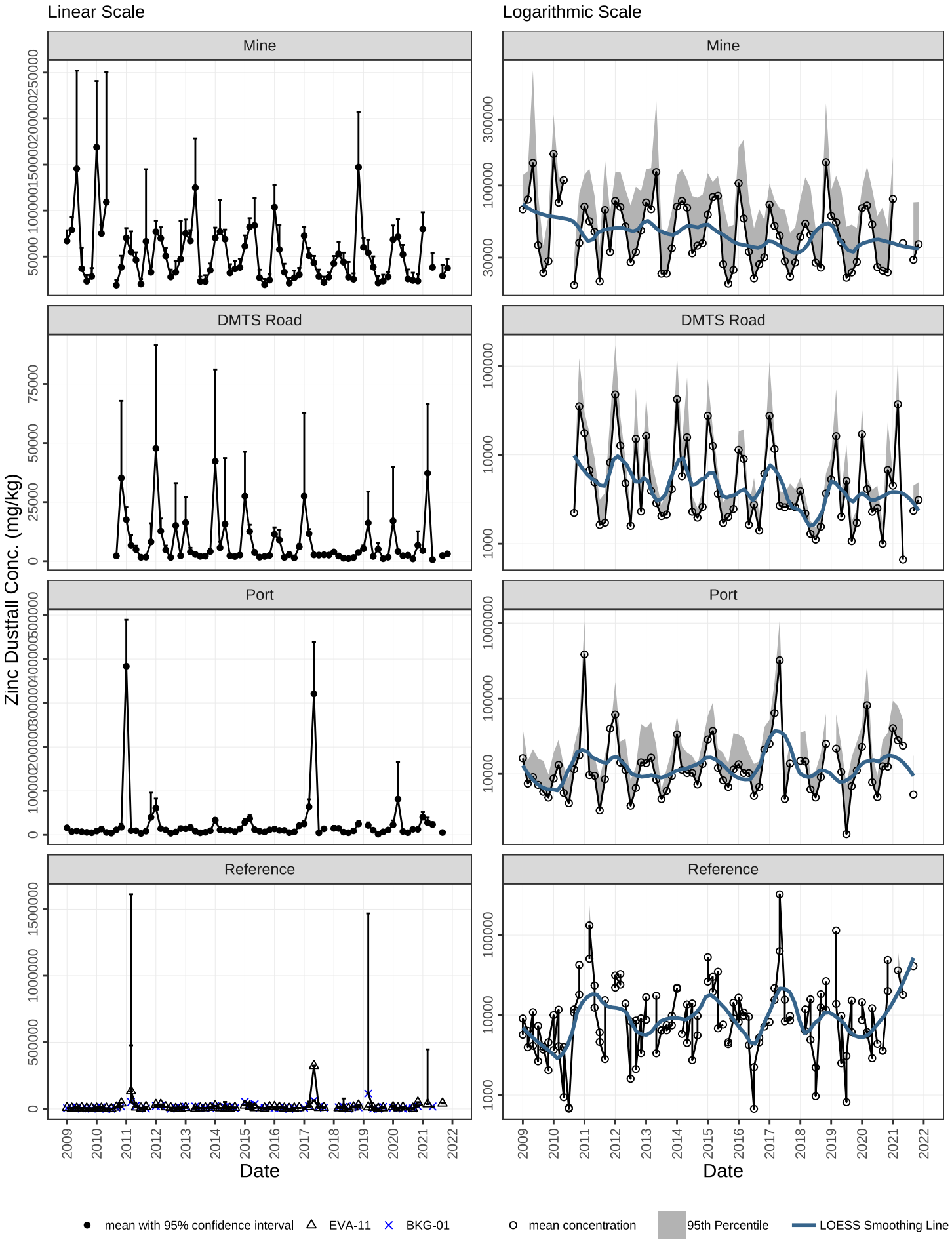

Figure 13. Dustfall Jars Zinc Conc. plots (all years)

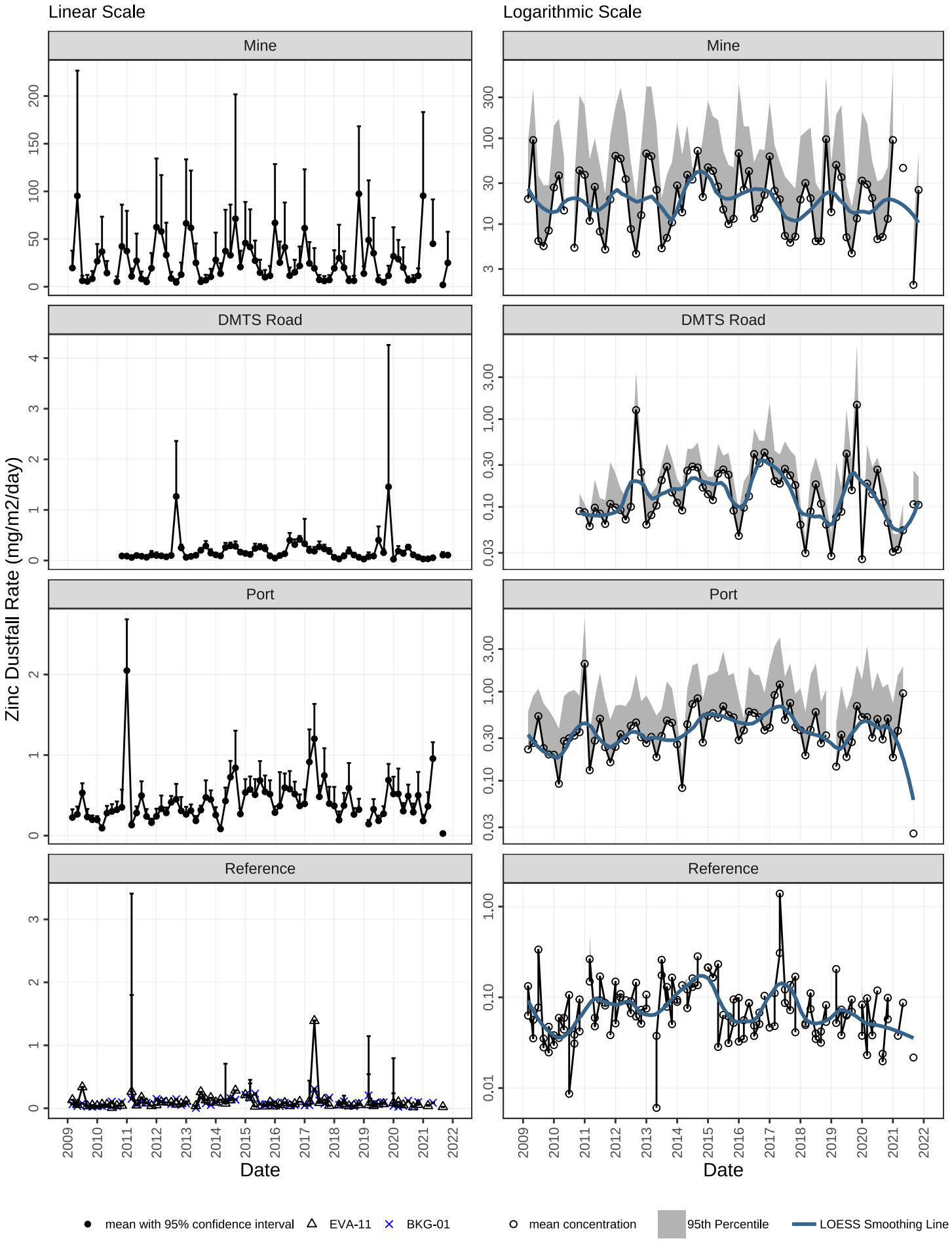

Figure 14. Dustfall Jars Zinc Rate plots (all years)

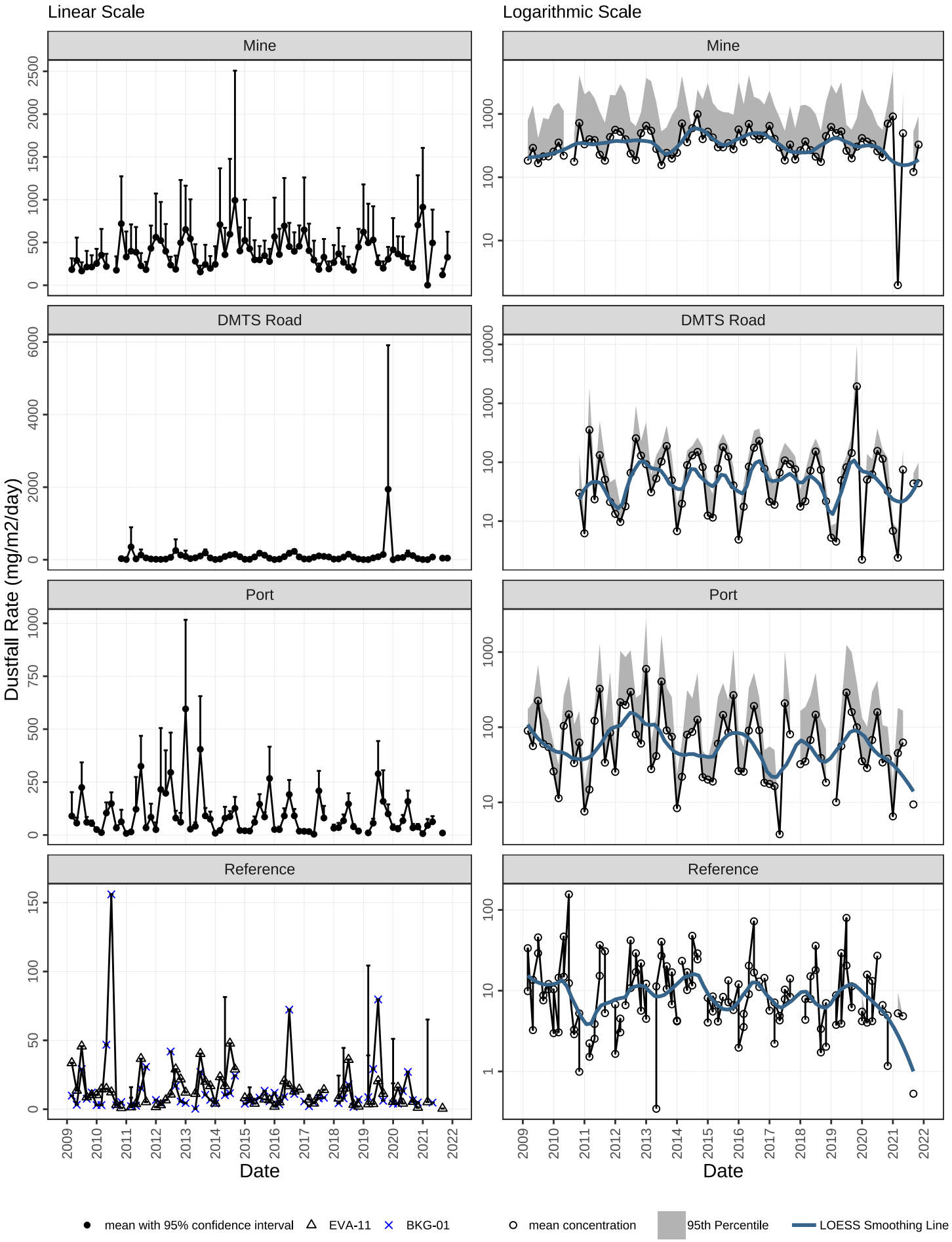

Figure 15. Dustfall Jars Solids Rate plots (all years)

Tables

Table 1. Partisol and TEOM concentration statistical trend analysis (Seasonal Mann-Kendall Trend Test)

For 1/2018 - 12/2021; Mean Concentration

LEAD	Concentration (µg/m^3)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.298	0.000425	Yes; Increasing
Mine T-Dam	-0.366	2.35E-05	Yes; Decreasing
Port CSB	-0.361	2.69E-05	Yes; Decreasing
Port Lagoon	-0.319	0.000282	Yes; Increasing
Port CSB & Lagoon	-0.36	2.06E-05	Yes; Decreasing

ZINC	Concentration (µg/m^3)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.28	0.000953	Yes; Increasing
Mine T-Dam	-0.366	2.35E-05	Yes; Decreasing
Port CSB	-0.331	0.000116	Yes; Increasing
Port Lagoon	-0.257	0.00349	Yes; Increasing
Port CSB & Lagoon	-0.317	0.000181	Yes; Increasing

[a] Significant at $p<0.05/2$ (i.e., $p<0.025$ with Bonferroni adjustment because multiple [2] related hypotheses are tested).

For 1/2018 - 12/2021; Top 95% Concentration

LEAD	Concentration (µg/m^3)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.292	0.000559	Yes; Increasing
Mine T-Dam	-0.373	1.67E-05	Yes; Decreasing
Port CSB	-0.364	0.000023	Yes; Decreasing
Port Lagoon	-0.303	0.00059	Yes; Increasing
Port CSB & Lagoon	-0.366	1.48E-05	Yes; Decreasing

ZINC	Concentration (µg/m^3)		
	tau statistic	p value	significant trend?[a]
Mine PAC	-0.255	0.00261	Yes; Increasing
Mine T-Dam	-0.373	1.67E-05	Yes; Decreasing
Port CSB	-0.305	0.000381	Yes; Increasing
Port Lagoon	-0.264	0.0027	Yes; Increasing
Port CSB & Lagoon	-0.304	0.000321	Yes; Increasing

[a] Significant at $p<0.05/2$ (i.e., $p<0.025$ with Bonferroni adjustment because multiple [2] related hypotheses are tested).

Table 2. Road surface concentration statistical trend analysis (Seasonal Mann-Kendall Trend Test)

For 1/2018 - 12/2021; Mean Concentration:

LEAD		Concentration (ppm)		
		tau statistic	p value	significant trend?[a]
Mine[b]	2018 - 2021	-0.323	0.0128	Yes; Decreasing
Port		-0.214	0.0874	No
Road		-0.333	0.0069	Yes; Decreasing
Mine CSB (Mine)		0.102	0.408	No
The Y (Mine)		-0.333	0.00789	Yes; Decreasing
Airport (Mine)		-0.26	0.045	No
MS-13 (Mine/Road)		-0.277	0.0275	No
MS-9 (Road)		-0.238	0.0537	No
R-Boundary (Road)		-0.374	0.00243	Yes; Decreasing
MS-2 (Port)		-0.343	0.00624	Yes; Decreasing
Port CSB Track (Port)		-0.163	0.194	No

ZINC		Concentration (ppm)		
		tau statistic	p value	significant trend?[a]
Mine[b]	2018 - 2021	0.228	0.0781	No
Port		-0.171	0.171	No
Road		-0.361	0.00348	Yes; Decreasing
Mine CSB (Mine)		0.714	7.09E-09	Yes; Increasing
The Y (Mine)		-0.319	0.011	Yes; Decreasing
Airport (Mine)		-0.26	0.045	No
MS-13 (Mine/Road)		-0.262	0.0365	No
MS-9 (Road)		-0.265	0.0315	No
R-Boundary (Road)		-0.374	0.00243	Yes; Decreasing
MS-2 (Port)		-0.343	0.00624	Yes; Decreasing
Port CSB Track (Port)		-0.0922	0.462	No

CADMIUM		Concentration (ppm)		
		tau statistic	p value	significant trend?[a]
Mine[b]	2018 - 2021	-0.0133	0.931	No
Port		-0.0824	0.578	No
Road		-0.156	0.283	No
Mine CSB (Mine)		-0.156	0.283	No
The Y (Mine)		-0.106	0.474	No
Airport (Mine)		-0.0133	0.931	No
MS-13 (Mine/Road)		-0.106	0.474	No
MS-9 (Road)		-0.111	0.443	No
R-Boundary (Road)		-0.156	0.283	No
MS-2 (Port)		-0.0353	0.812	No
Port CSB Track (Port)		-0.106	0.474	No

[a]Significant at $p<0.05/3$ (i.e., $p<0.017$ with Bonferroni adjustment because multiple [3] related hypotheses are tested)

[b]MS-13 included in Mine

Table 3. Dustfall rate and concentrations statistical trend analysis (Seasonal Mann-Kendall Trend Test)

For 1/2018 - 12/2021; Mean Deposition Rate and Concentration:

LEAD	Dustfall Desposition Rate (mg/m^2/day)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.0676	0.467	No	0.417	0.0000072	Yes; Increasing
DMTS Road	-0.0396	0.67	No	0.0303	0.744	No
Port	0.0207	0.828	No	0.155	0.103	No
Reference	0.0526	0.589	No	0.28	0.00406	Yes; Increasing

ZINC	Dustfall Desposition Rate (mg/m^2/day)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.0338	0.718	No	0.812	0	Yes; Increasing
DMTS Road	-0.035	0.707	No	0.021	0.821	No
Port	0.0259	0.786	No	0.285	0.00282	Yes; Increasing
Reference	0.0416	0.67	No	0.324	0.000873	Yes; Increasing

TOTAL SOLIDS	Dustfall Desposition Rate (mg/m^2/day)		
	tau statistic	p value	significant trend?[a]
Mine	-0.0396	0.67	No
DMTS Road	-0.0443	0.634	No
Port	0.0104	0.914	No
Reference	0.0305	0.754	No

[a] Significant at p<0.05/3 (i.e., p<0.017 with Bonferroni adjustment because multiple [3] related hypotheses are tested).

For 1/2018 - 12/2021; Top 95% Deposition Rate and Concentration:

LEAD	Dustfall Deposition Rate (mg/m^2/day)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.0676	0.467	No	0.622	2.17E-11	Yes; Increasing
DMTS Road	-0.049	0.599	No	0.166	0.0751	No
Port	-0.00518	0.957	No	0.394	0.0000368	Yes; Increasing
Reference	0.0582	0.55	No	0.438	0.00000691	Yes; Increasing

ZINC	Dustfall Deposition Rate (mg/m^2/day)			Concentration (mg/kg-total solid)		
	tau statistic	p value	significant trend?[a]	tau statistic	p value	significant trend?[a]
Mine	-0.0338	0.718	No	0.831	0	Yes; Increasing
DMTS Road	-0.0396	0.67	No	0.138	0.139	No
Port	0.0311	0.745	No	0.611	1.48E-10	Yes; Increasing
Reference	0.036	0.712	No	0.38	0.0000972	Yes; Increasing

TOTAL SOLIDS	Dustfall Deposition Rate (mg/m^2/day)		
	tau statistic	p value	significant trend?[a]
Mine	-0.0676	0.467	No
DMTS Road	-0.0396	0.67	No
Port	-0.00518	0.957	No
Reference	0.0305	0.754	No

[a] Significant at p<0.05/3 (i.e., p<0.017 with Bonferroni adjustment because multiple [3] related hypotheses are tested).

Table 4. Summary of dust monitoring trends

For most recent 4 years (2018-2021)																	
Location and Measure	Road Surface (Concentration)			Location and Measure	Paritsol & TEOM (Air Concentration)				Location and Measure	Dustfall Jars (Concentration and Deposition Rate)					
	Mean				Mean		95th Percentile			Mean			95th Percentile		
	Pb	Zn	Cd[c]		Pb	Zn	Pb	Zn		Pb	Zn	Solids	Pb	Zn	Solids
Mine[b] (Conc.)	↘	—	—	Mine PAC (Conc.)	↗	↗	↗	↗	Mine (Conc.)	↗	↗	a	↗	↗	a
				Mine TDam (Conc.)	↘	↘	↘	↘	Mine (Rate)	—	—	—	—	—	—
Road (Conc.)	↘	↘	—						Road (Conc.)	—	—	a	—	—	a
									Road (Rate)	—	—	—	—	—	—
Port (Conc.)	—	—	—	Port CSB (Conc.)	↘	↗	↘	↗	Port (Conc.)	—	↗	a	↗	↗	a
				Port Lagoon (Conc.)	↗	↗	↗	↗	Port (Rate)	—	—	—	—	—	—
				Port CSB & Lagoon (Conc.)	↘	↗	↘	↗							
									Reference (Conc.)	↗	↗	a	↗	↗	a
									Reference (Rate)	—	—	—	—	—	—

[a] Concentration is not evaluated for solids, because total solids is the entire sample mass.

[b] MS-13 included in Mine

[c] No Cadmium data since 2018 so trends have not changed

1. Results are presented for statistical testing using data from the past four years.

Notes:

— Indicates no statistically significant change over time period tested (trend is FLAT).

↗ Indicates a statistically significant increase over time period tested (trend is UP).

↘ Indicates a statistically significant decrease over time period tested (trend is DOWN).

TEOM = tapered element oscillating microbalance (air sampling device)

Conc = air concentration (TEOM air sampling) or concentration in dustfall (dustfall jars)

Rate = dustfall deposition rate based on dustfall jar measurements

TDam = mine tailings dam

PAC = personnel accommodations complex

CSB = concentrate storage building

Appendix A

IVBA Results, Response to Comments, and Raw Data Tables

RESEARCH NOTE

Effect of time and soil particle size on the in vitro bioaccessibility of aluminum and barium in Arctic tundra soils

Johanna Salatas[1], Yvette Lowney[2],

[1]Teck Alaska Incorporated, Anchorage, Alaska, USA

[2] Alloy LLC, Boulder, Colorado, USA

Keywords

Bioaccessibility, bioavailability, metals, Arctic soils, tundra, aluminum, barium

Correspondence

Johanna Salatas, Teck Alaska Incorporated, E-mail: johanna.salatas@teck.com

Abbreviations

Al: aluminum, As: arsenic, Ba: barium, DMTS: DeLong Mountain Regional Transportation System, DTSC: Department of Toxic Substances Control, EPA: U.S. Environmental Protection Agency, RDO: Red Dog Operations, ICP-MS: inductively coupled plasma mass spectrometry, ICP-OES: inductively coupled plasma-optical emission spectroscopy, IVBA: in vitro bioaccessibility, ISO: International Organization for Standardization, ITRC: Interstate Technology Regulatory Council, QA: quality assurance, Pb: lead, Zn: zinc

---

Abstract

Red Dog Operations (RDO), located in the western Brooks Mountain Range in Northwest Alaska, is one of the largest producing zinc mines in the world. The surrounding area is characterized by Arctic tundra ecosystem, dominated by mixed shrub-sedge tussock tundra interspersed with low-lying, well-drained knolls that support a variety of lichen, forbs, and shrubs. Arctic tundra soils were sampled near RDO to measure the concentrations and in vitro bioaccessibility (IVBA) of aluminum (Al) and barium (Ba), which were indicated as potential contributors toward ecological risk in the RDO fugitive dust risk assessment that was completed in 2007. Al and Ba concentrations and IVBA were measured for two soil particle size fractions. The objectives were to evaluate changes in metals concentrations and bioaccessibility between 2005 and 2018, and to assess whether the measured bioaccessibility in these soils is affected by soil particle size. Results of this study showed little change in Ba soil concentrations and decreases in Al concentrations over time. The IVBA of these metals was shown to be low and did not substantially change between the two time periods. Soil particle size did not predictably affect either the

concentrations or the IVBA of these metals in tundra soils. The results of this study provide information to fill potentially important data gaps in the literature related to the environmental fate and stability of metals in soils in general, and from Arctic regions specifically.

Introduction

A large body of research exists regarding the environmental chemistry of metals in soils and their bioavailability, and how such data can be used to inform human and ecological risk assessment. Such research indicates that metals in soil can be present in forms that are not fully bioavailable, and in particular, not as bioavailable as the forms of metals used in laboratory toxicity testing. This is generally well established for metals and metalloids in mine waste where bioavailability is affected by the mineral form of the metal, soil particle size, and by soil characteristics that can encapsulate or otherwise affect the solubility of metals under physiological conditions (Ruby et al. 1999, Shock et al. 2007, U.S. EPA 2007a, b; Menzie et al. 2008, 2009; ITRC 2017). This study presents the results of an investigation of the IVBA of Al and Ba from soils collected from tundra locations near Red Dog Mine, which is located in a remote tundra environment in northwest Alaska above the Arctic Circle. Al and Ba were studied because previous assessments that assumed 100% bioavailability for these metals indicated potentially increased risk from Al and Ba exposure for animals in the vicinity of the mine and associated transportation corridor (Shock et al., 2007; Exponent, 2007).

Bioavailability studies are typically conducted in animals. However, animal ("in vivo") studies are expensive, time consuming, and may raise ethical concerns. Therefore, laboratory methods have been developed to provide more efficient and inexpensive mechanisms to estimate the oral bioavailability of metals in soils relative to soluble forms. In vitro approaches include many different methods, generally intended to mimic conditions of the gastrointestinal tract (i.e., physiologically based). These methods rely on laboratory extraction testing of soil to assess the fraction of total chemical released, and the results are referred to in the published literature as bioelution, bioaccessibility, and IVBA.

IVBA results are used to estimate the relative bioavailability of chemicals from soil. Relative bioavailability is the ratio of the fraction of metal absorbed from soil compared to the fraction absorbed from the exposure medium used in the toxicity studies that form the basis for the default reference dose for estimating human toxicity (Schoof 2003) and the toxicity reference values (TRVs) that are used to evaluate toxicity to ecological receptors (Shock et al. 2007).

Regulatory agencies recognize that soil-chemical interactions may result in the reduced bioavailability of certain chemicals from soil and therefore adjustments are accepted to account for this in the risk assessment process for both human and ecological receptors (U.S. EPA 1998, 2007a, 2007b, 2007c, 2017; ITRC 2017, ISO 2018, California DTSC 2020, Whitacre et al. 2017; Hawaii Department of Health 2020; Health Canada 2017). Adjustments based on site-specific bioavailability are used to refine the results of a risk assessment by reducing uncertainties in the exposure assessment and associated risk characterization.

Study Background

Red Dog Mine is an operation using conventional drill and blast mining methods, and includes a mill where concentrates are produced through crushing and grinding. The mine is located on land owned by NANA, a for-profit Alaska Native Corporation, and was developed under an innovative operating agreement between NANA and the mine operator, Teck Alaska. The concentrates are trucked along a 52-mile gravel haul road from the mine site to the coast, and delivered to the Chukchi Sea port facility for shipment to markets around the world. The haul road and the port collectively make up the DeLong Mountain Regional Transportation System (DMTS), built by the Alaska Industrial Development and Export Authority (AIDEA) and completed in 1989.

During the early 2000s, a comprehensive human health and ecological risk assessment was conducted for tundra areas surrounding the DMTS and RDO. The bioavailability of all metals except lead (Pb) was assumed to be 100%; for Pb, adjustments were made in the human health risk assessment to account for its site-specific bioavailability (Exponent 2007, Garry et al. 2020). The ecological risk assessment, which assumed metals were 100% bioavailable from soil, showed a potential for increased risk to small

81 mammals from exposure to Al and Ba, with incidental ingestion of soil being the primary exposure
82 pathway (Exponent 2007, Shock et al. 2007). To further refine the results and reduce uncertainties
83 associated with the risk assessment, the site-specific Al and Ba bioaccessibility was evaluated in 2005
84 using in vitro methods as described in Shock et al. (2007). The Shock et al. (2007) study showed the
85 bioavailability (as estimated by IVBA) of Al and Ba from soils was substantially less than the default
86 assumption of 100%. Therefore, actual potential for adverse effects from these metals was concluded to
87 be small given the highly conservative nature of the risk assessment (Exponent 2007).
88
89 The information in this brief communication is specifically focused on summarizing the results of
90 follow up IVBA testing for a small set of Arctic tundra soils affected by fugitive dust from RDO. The
91 objectives were to determine whether the bioaccessibility of Al and Ba in these samples differs as a
92 function of soil particle size, and to determine if there have been changes in the concentrations and
93 bioaccessibility of these metals over time. Soil sampling was conducted in 2018, with sampling locations
94 selected to replicate the locations where soils were sampled previously in 2005. The IVBA of Ba and Al
95 were measured for different soil particle size fractions.
96 To provide information on the bioavailability of Al and Ba for these Arctic tundra soil samples, IVBA
97 extractions of samples were conducted under the conditions specified by U.S. Environmental Protection
98 Agency (EPA) Method 1340. This method has been validated for quantitative use in predicting relative
99 oral bioavailability of Pb and arsenic (As) for human health risk assessment (U.S. EPA 2017). Other
100 investigations have also established that the acidic extraction conditions used in EPA Method 1340 also
101 generate data that are generally predictive of the bioavailability of cadmium (Cd), for which an
102 International Organization for Standardization (ISO) Standard has been developed (ISO 2018; Schroder et
103 al. 2003; Boros et al. 2017). Similarly, investigations by Health Canada indicate that a low pH extraction
104 method, such as EPA Method 1340, results in the most conservative estimate of IVBA for zinc (Zn)
105 (Koch et al. 2013). Therefore, while validated by U.S. EPA (2018) for Pb and As only, EPA Method 1340
106 can also provide screening information for the bioavailability of other metals (Menzie et al. 2008).

Although limited in scope to only a few available samples, this study provides information to fill data gaps in the literature that have been identified by several researchers, including gaps in information on metals in Arctic environments and the stability of soil-chemical interactions over time (Rudnika-Kepa and Zaborska 2021, Fernandez-Llamazares 2019, Camenzuli et al. 2014, Darrouzet-Nardi 2018, Sloan et al. 1997, Violante et al. 2010, Rieuwerts et al. 1998, Liang et al. 2016, Bradham et al. 2018, Cipullo et al. 2018, Basta 2020, Hanley 2020, Scheckel et al. 2019, Menzie et al. 2008). In addition to addressing these data gaps, this study provides an example of combining information across scientific disciplines to yield findings that are important to regulatory decision making. For example, it has been hypothesized that rapidly changing climatic conditions including the thawing of permafrost may affect the stability of contaminant and nutrient cycles in the Arctic tundra (Alekseev et al. 2021). However, soil studies from Arctic locations near human populations that rely on subsistence hunting, harvesting, and fishing remain severely under-represented, and available data on metals in Alaskan soil are insufficient to assess exposure in such populations (Perryman et al. 2020, Camenzuli et al. 2014; Cipullo et al. 2018; Yang et al. 2016). This study addresses data gaps by combining information across scientific disciplines to yield findings that are important to regulatory decision making.

Materials and Methods

A brief description of the sample collection and IVBA extraction methods is provided below. For a more robust discussion of the methods employed herein, the reader is directed to Shock et al (2007).

Soil Sample Collection

Two tundra soil grab samples were collected during June and July 2018 for metals analysis and IVBA testing. Samples were collected from locations previously sampled in 2005 to allow temporal comparison with the results reported by Shock et al. (2007). One of the sampling sites was located approximately 2000 m to 3000 m downwind of the active mine area, where Ba-enriched dust deposition likely occurred. This sample is referred to as the “mine sample” or “mine location.” The other sampling site was located

approximately 10 m downwind from the DMTS transport road, where windblown dust from the road and truck traffic was deposited (Figure 1). This sample is referred to as the "road sample" or "road location."

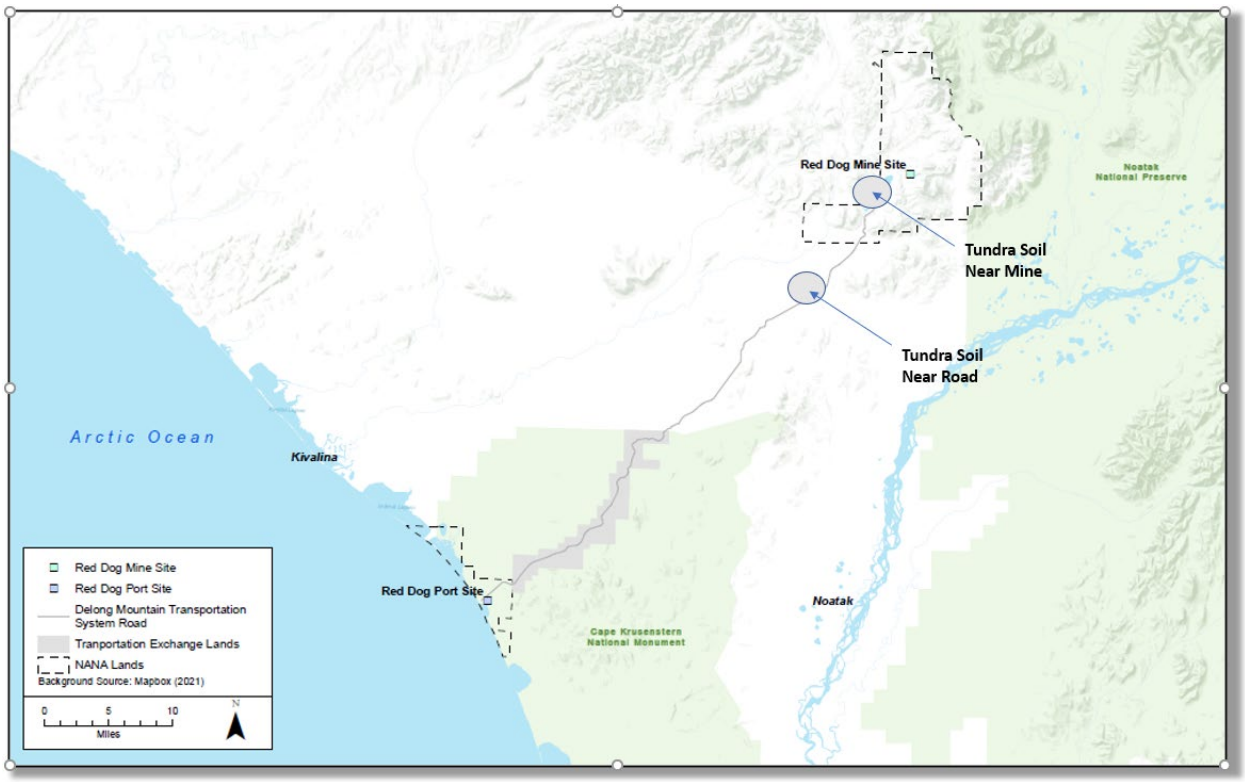

Figure 1: Study area with locations of tundra soil samples

In both 2005 and 2018, the soil samples were collected from the top 0–2 cm of the soil horizon beneath the tundra vegetation mat. In both sampling efforts, where necessary, vegetation was pulled aside to access the underlying peaty organic soil. Soils were shipped to the lab in sealed bags, where they were air dried and sieved to the target particle size fractions, <2 mm and <250 µm. The particle size fractions were targeted to be consistent with the 2005 data collection. Sample preparation, extraction, and analysis are more completely described in Shock et al. (2007).

Total Metals Determination

To remain consistent with the prior data collection methods and to allow comparison between the 2005 and 2018 datasets, laboratory X-ray fluorescence analysis (XRF) was used to measure the total Al and Ba concentrations in the soil samples.

In Vitro Bioaccessibility Testing

IVBA testing was conducted following U.S. EPA Method 1340. This protocol involves extracting a 1-g aliquot of the test soil in 100 mL of buffered extraction fluid (i.e., simulated gastric fluid) at pH 1.5 for one hour with end-over-end rotation. IVBA extraction fluid was analyzed in 2018 using inductively coupled plasma mass spectrometry (ICP-MS)[1]. At the end of the extraction process, the mass of metal extracted was compared to the total mass of the metal in a separate aliquot of the test material. IVBA was calculated and expressed on a percentage basis using the following equation:

$metal_{ext}$ = in vitro extractable metal in the in vitro extract (mg/L)
V_{ext} = extraction solution volume (L)
$Metal_{soil}$ = metal concentration in the soil sample being assayed (mg/kg)
$Soil_{mass}$ = mass of soil sample being assayed (kg)

Results and Discussion

Tables 1 and 2 provide a summary of the 2005 and 2018 total metals concentrations and the IVBA extraction testing results for the two different soil particle size fractions, for Al and Ba, respectively.

Aluminum

Particle size had no consistent influence on the concentration or bioaccessibility (as measured by IVBA) of Al in tundra soils collected from either time period (Table 1)[2]. Al soil concentrations as measured in 2018 were lower in both the road and mine samples relative to samples collected from the same locations in 2005 (Table 1), suggesting a decrease in Al concentration over time with the greatest

[1] This differs from 2005 where the extracts were analyzed using inductively coupled plasma-optical emission spectroscopy (ICP-OES) following a modified version of EPA Method 6010B (Shock et al. 2007).

[2] Al concentration was not measured in the <2 mm particle size fraction due to low mass of the 2018 sample

167 decrease observed for the road location. The bioaccessibility of Al from tundra soils was very low, for
168 both the 2005 and 2018 samples: with IVBA ranging from 1.3% to 5.5% for the 2018 samples and from
169 0.5% to 3.3% for the 2005 samples (Table 1). The data from both years indicate that the bioaccessibility
170 of Al is not strongly dependent on soil particle size, though a small decrease in IVBA was observed with
171 decreasing particle size for soil samples from both years.
172

Table 1: Comparison of aluminum concentrations and bioaccessibility (IVBA)

Sample Location[a] and Particle Size	Total Al in Soil by XRF[b] (mg/kg)	IVBA[c] (%)	Bias-Adj IVBA[d] (%)
Tundra Soil Near Road			
<2mm Particle Size Fraction			
2018 Soil Sample	14000	1.4	0.5
2005 Soil Sample	32100	0.5	
<250µm Particle Size Fraction			
2018 Soil Sample	13800	1.3	0.5
2005 Soil Sample	32300	0.5	
Tundra Soil Near Mine			
<2mm Particle Size Fraction			
2018 Soil Sample	26800[e]	5.5	2.2
2005 Soil Sample	32600	3.3	
<250µm Particle Size Fraction			
2018 Soil Sample	26800	5.3	2.1
2005 Soil Sample	34000	3.2	

Notes:

[a] Data for 2005 samples are from Shock et al. (2007); data for solid:fluid ratio of 1:100

[b] Total metals result by X-ray fluorescence at The Mineral Lab

[b] IVBA result calculated using total metals result with hydrofluoric acid digestion at TestAmerica

[c] IVBA represents mass extracted divided by total mass in soil sample tested, per EPA Method 1340

[d] IVBA value corrected for analytical bias; see text for discussion

[e] Not measured due to low sample mass in <2mm fraction; value here represents results for <250µm

173

Under the standard IVBA extraction methods there were "interferences" between components of the extraction fluid and the Al mass in that fluid (ACZ Laboratory personal communication)[3]. These interferences result in reported concentrations of Al in the extraction fluid that are biased high. Quality assurance (QA) data from 2018 showed that ICP-MS recovery of Al spiked into the IVBA extraction fluid was 152% to 388%, indicating the reported IVBA values are overestimated. Table 1 presents both the original, unadjusted IVBA values and values adjusted by a factor of 2.5 for the high bias (based on the average recovery across triplicate samples, 247%, or a factor of approximately 2.5). For samples collected in 2005 (reported by Shock et al. 2007), bias was not an issue because the IVBA fluid was analyzed using ICP-OES. For any future efforts related to determination of Al IVBA, this potential for bias should be considered in the selection of an analytical lab and the type of instrumentation. When adjusted for the analytical bias, the bioaccessibility of Al from the 2018 soil samples was the same or lower than that measured in samples from matched locations in 2005.

Barium

There was no consistent effect of soil particle size on either the concentration or bioaccessibility of Ba in soils collected from either year (Table 2)[4]. Ba soil concentrations were similar between 2005 and 2018: concentrations ranged from 3,000 mg/kg to 6,300 mg/kg in 2018 samples, and from 2,990 mg/kg to 8,560 for samples collected in 2005. As was seen with Al, Ba soil concentrations were higher in mine samples as compared to those from the road location. As with the results for Al, the reported bioaccessibility of Ba was low for soil samples collected from both time periods: with IVBA ranging from 11% to 22% for the 2018 samples, and from 12% to 20% for the 2005 samples (Table 2). Ba bioaccessibility was greater in road samples collected in 2018 as compared to 2005 samples from the

---

[3] According to the analytical laboratory: "*The IVBA extraction and analysis procedure has not been optimized for aluminum. Having off-method analytes out of control limits is not unusual considering the IVBA extraction matrix is made of pH adjusted glycine, which behaves differently in the ICP-MS plasma than in an acidified DI [deionized] water blank. Glycine contains lots of carbon, and carbon enhances the energy in the plasma, causing some elements to be biased high, while other elements will see less bias. This is due to varying elemental ionization potentials. Since the laboratory fortified blank (LFB) and the matrix spike (MS) samples showed high bias for Al, one could assume all results are biased high for those analytes.*"

[4] As with Al, the Ba concentration could not be measured in the <2 mm particle size fraction due to low mass of the 2018 sample.

195 same location, but the same trend was not seen for the mine samples. There was no analytical bias for the

196 Ba IVBA samples.

197

198

Table 2: Comparison of barium concentrations and bioaccessibility (IVBA)

Sample Location[a] and Particle Size	Total Al in Soil by XRF[b] (mg/kg)	IVBA[c] (%)
Tundra Soil Near Road		
<2mm Particle Size Fraction		
2018 Soil Sample	3000	22
2005 Soil Sample	3230	12
<250µm Particle Size Fraction		
2018 Soil Sample	3200	21
2005 Soil Sample	2990	13
Tundra Soil Near Mine		
<2mm Particle Size Fraction		
2018 Soil Sample	6300[d]	13
2005 Soil Sample	8560	13
<250µm Particle Size Fraction		
2018 Soil Sample	6300	11
2005 Soil Sample	6160	20

Notes:

[a] Data for 2005 samples are from Shock et al. (2007); data for solid:fluid ratio of 1:100

[b] Total metals result by X-ray fluorescence at The Mineral Lab

[b] IVBA result calculated using total metals result with hydrofluoric acid digestion at TestAmerica

[c] IVBA represents mass extracted divided by total mass in soil sample tested, per EPA Method 1340

[d] Not measured due to low sample mass in <2mm fraction; value here represents results for <250µm

199

200 ***Effect of Time on Bioaccessibility***

201 Although adjustments for bioavailability are sometimes incorporated into ecological and human

202 health risk assessments, few studies have documented the stability of metals bioavailability in soils over

203 time. Liang et al. (2016) and Xu et al. (2019) conducted short-term studies that evaluated changes over

204 time in IVBA for soils spiked with soluble lead, arsenic, and cadmium in the laboratory. Bioaccessibility

205 initially decreased, especially in the first month after spiking, and then stabilized after 76 weeks under

206 controlled laboratory conditions. Studies on chemical amendments added to soils with the specific
207 intention of reducing the bioavailability of contaminants (e.g., Scheckel et al. 2005 and 2013; Ryan et al.
208 2004, Scheckel and Ryan 2004) have investigated changes in metals bioaccessibility over time. These
209 authors specifically discuss the limitations associated with these bench-scale laboratory experiments and
210 the "general lack of field-scale testing" which make it difficult to translate these results to the natural
211 environment.

212 A query of researchers and regulators indicates that assessing temporal changes in the bioavailability
213 of chemicals from soils in the natural environment has been largely unstudied (Hanley, personal
214 communication). Academic researchers involved in this field over the last several decades note that short
215 term decreases in bioavailability have been established for soils under laboratory conditions and for tests
216 with chemically amended soils, but data from long-term in situ studies are lacking (Basta, personal
217 communication). Bradham et al. (2018) conducted long-term in situ studies on soils in Joplin, Missouri,
218 where different soil amendments were tested for their ability to reduce the bioavailability of Pb. Their
219 research suggests that specific soil amendments effectively reduced Pb bioavailability, which remained
220 stable for 16 years after treatment.

221 To our knowledge, this study is one of the first to examine the IVBA of Al and Ba from soils in a
222 natural environment over time. Results of this study suggest that for the Arctic tundra soils in the vicinity
223 of Red Dog Mine, the bioavailability of these metals (as approximated by IVBA) has remained generally
224 stable over the more than a decade.

225 ***Bioavailability in Arctic Environments***

226 Few studies have evaluated the bioaccessibility of metals from tundra soils. Brumbaugh et al. (2011)
227 collected vegetation and dust samples along the DMTS haul road as it passes through Cape Krusenstern
228 Nation Monument and evaluated the samples for metals bioaccessibility using the same IVBA methods as
229 this study. They reported low to intermediate (20% to 40%) bioaccessibility of Ba from road dust and
230 vegetation and relatively low (<6%) bioaccessibility of Al. Brumbaugh et al. (2011), the bioaccessibility
231 results are limited to dusts and vegetation (rather than the subsurface peat samples that most closely

match the matrix reported here), thus precluding direct comparison across studies. Nevertheless, results from both studies suggest low bioaccessibility of Al and Ba. It has been hypothesized that rapidly changing climatic conditions may affect the stability of contaminant and nutrient cycles in the Arctic tundra (Alekseev et al. 2021, Perryman et al. 2020, Camenzuli et al. 2014, Cipullo et al. 2018, Yang et al. 2016). These studies have found that data on metals concentrations in Arctic soils from areas near subsistence communities are lacking, and the authors have identified a critical need for such studies in areas with continuous permafrost.

Permafrost-affected soils in the Arctic occupy a significant land area and are notably unique compared to soils from other geographical regions (Alekseev et al. 2021). Research documenting the behavior of metals and metalloids in Artic ecosystems has been labeled as of "great interest" and data that can enhance the environmental management of these areas is of "crucial" social and economic importance (Tregubova et al. 2021). Perryman et al. (2020) cautioned that critical gaps exist for metals data for continuous permafrost zones in Northern Alaska. In a review of remediation technologies for metals-contaminated sites in polar regions, Camenzuli et al. (2014) illustrated the unique factors affecting this environment, pointing out that environmental contamination from human activities "remains understudied and unresolved in many polar regions." Complex chemical and biological interactions (e.g., pH, competitive sorption/desorption, precipitation, microbial metabolism, oxidation/reduction) are known to influence the mobility of metals from soils in the natural environment. These factors and the studies mentioned above illustrate the importance and need for in situ studies of the nature and stability of contaminants in Arctic environments. This study on the bioaccessibility of Al and Ba from Arctic tundra soils can help fill such data gaps.

Effects of Soil Particle Size

Investigations into the soil-chemical interactions that affect the solubility and bioavailability of metals from soil have long indicated that soil particle size can be an important consideration, and that the higher surface area ratio of small particles can sometimes result in greater liberation of metals (Ruby et al. 1999, U.S. EPA 2007a, Karna et al. 2017). Research also indicates that such relationships may also depend on

258 other factors such as site-specific soil characteristics (e.g., Ruby et al. 1999, U.S. EPA 2007a , Li et al.
259 2019, Ma et al. 2019, Ljung et al. 2007, Quin et al. 2016). Such considerations may be particularly
260 important for understanding the potential human health risks from exposures to contaminants in soil
261 because typically, smaller soil particle size more accurately represent the fraction of soil that is
262 incidentally ingested (Ruby and Lowney 2012, U.S. EPA 2016).

263 Our study showed little effect of soil particle size on either Al and Ba concentrations or IVBA. This
264 observation is consistent for samples collected in both 2005 and 2018, based on the <250 µm and <2 mm
265 particle size fractions. The smaller particle size fraction now recommended by U.S. EPA (2016) for use in
266 human health risk assessments, <150 µm, should be considered for future studies examining the effects of
267 soil particle size on IVBA, although the data reported here for Al and Ba suggest that there may be little
268 difference.

269 Summary and Conclusions

270 The primary objectives for this study were to determine if the concentrations and bioaccessibility of
271 Al and Ba in Arctic tundra soils collected from two locations near Red Dog Mine changed over time, and
272 to assess whether soil particle size had any influence over these metrics. The data from this study show:

273 - Al tundra soil concentrations were lower in 2018 as compared to in 2005, while Ba
274 concentrations generally remained the same over time.

275 - The bioaccessibility of Al and Ba from tundra soils collected in the vicinity of Red Dog Mine and
276 its transportation corridor is low (maximum 5.5% unadjusted IVBA for Al, and maximum 22%
277 IVBA for Ba).

278 - A small decrease in Al bioaccessibility was observed with decreasing particle size for soil
279 samples from both years, but soil particle size did not predictably affect the concentrations or
280 bioaccessibility of Al or Ba.

- While there were slight differences in the measured bioaccessibility of Al from the two time points, the IVBA values are all very low, suggesting little to no change in the bioaccessibility of Al from the tundra soils over time.
- Ba bioaccessibility was greater in road samples collected in 2018 as compared to 2005 samples from the same location.
- Analytical bias affected the IVBA results for Al but not Ba; potential for bias should be considered when selecting an analytical lab and the type of instrumentation in future studies.

This investigation of whether Al and Ba tundra soil concentrations and bioaccessibility changed over time or were related to soil particle size was conducted as part of the ongoing RDO fugitive dust risk management program. Uncertainty reduction studies combined with monitoring results such as these are used by RDO to verify the effectiveness of fugitive dust best management practices and operational improvements, and to inform nearby communities that utilize the areas surrounding RDO for subsistence hunting and gathering. The IVBA data reported in Shock et al. (2007) and the data from this study indicate that the bioavailability of Al and Ba from tundra soils is likely to be substantially lower than the default assumption of 100% bioavailability used in the fugitive dust risk assessment. This illustrates the importance for incorporating bioavailability adjustments for risk assessment of Arctic soils.

This study provides information on the concentrations and bioaccessibility of Al and Ba in Arctic tundra soils, a topic that multiple researchers, regulators, health scientists, and soil scientists have identified as a data gap. Another unique aspect of this study is that it provides information about the in-situ stability of the concentrations and IVBA of the two metals in Arctic soils over time. The bioavailability of Al and Ba from tundra soils, as approximated by IVBA, is relatively low and has not changed substantially since 2005. The information provided in this study along with the study by Shock et al. (2007) improves the understanding of Al and Ba bioaccessibility from soils and can be used to refine the results of human health and ecological risk assessments at mining sites. In addition, considerations

regarding analytical methods and particle size effects, along with information that is specific to Arctic tundra soils may be used to inform future investigations.

References

Alekseev I., A. Zverev, E. Abakumov. 2021. Organic Carbon and microbiome in tundra and forest-tundra permafrost soils, southern Yamal, Russia. Polar Research. 40:5283.

Basta N. 2020. Professor, Ohio State SENR Natural Resources. Personal communication. basta.4@osu.edu

Bradham K.D., G.L. Diamond, C.M. Nelson, M. Noerpel, K.G. Scheckel, B Elek, R.L. Chaney, Q Ma, D.J. Thomas. 2018. Long-term in situ reduction of soil lead bioavailability measured in a mouse model. Environ. Sci. Toxicol. 2018, 52, 13908−13913.

Boros K, D. Fortin, I. Jayawardene, M. Chénier, C. Levesque, P.E. Rasmussen. 2017. Comparison of gastric versus gastrointestinal PBET extractions for estimating oral bioaccessibility of metals in house dust. Int J Environ Res Public Health. 14(1):92. doi: 10.3390/ijerph14010092.

Brumbaugh W.G., SA. Morman, and TW May. 2011. Concentrations and bioaccessibility of metals in vegetation and dust near a mining haul road, Cape Krusenstern Nation Monument, Alaska. Environ Monit Assess. Nov;182(1-4):325-40. doi:10.1007/s10661-011-1879-z.

California Department of Toxic Substance Control 2020. Arsenic Relative Bioavailability Study. https://dtsc.ca.gov/arsenic-relative-bioavailability-study/

Camenzuli D., B.L. Freidman, T.M. Statham, K.A. Mumford & D.B. Gore. 2014. On-site and in situ remediation technologies applicable to metal-contaminated sites in Antarctica and the Arctic: a review, Polar Research 32:1, 21522. https://doi.org/10.3402/polar.v32.21522

Cipullo S., G. Prpich, P. Campo, F. Coulon. 2018. Assessing bioavailability of complex chemical mixtures in contaminated soils: Progress made and research needs Sci. Tot. Environ. 615: 708-723. https://doi.org/10.1016/j.scitotenv.2017.09.321

329 Darrouzet-Nardi, A., S.C. Reed, E.E. Grote, J. Belnap. 2018. Patterns of longer-term climate change
330 effects on CO2 efflux from biocrusted soils differ from those observed in the short-term. Biogeosciences
331 15:4561–4573. 10.5194/bg-15-4561-2018
332 Fernandez-Llamazares, M. Garteizgogeascoa, N Basu, E Sonnenwend Brondizio, M. Cabeza, J.
333 Martinez-Alier, P. McElwee, V Reyes-Garcia. 2019. State of the art review of indigenous peoples and
334 environmental pollution. Integrated Environmental Assessment and Management. 16(3): 324-341.
335 Exponent. 2007. DMTS Fugitive Dust Risk Assessment, Volume I – Report. Prepared for Teck
336 Cominco Alaska Incorporated. Prepared by Exponent, Bellevue, WA. November 2007.
337 Garry, M.R., S.S. Shock, J. Salatas (2020) Human health risk assessment of metals exposure through
338 subsistence foods consumption and subsistence harvest activities near a mining transport road in
339 northwest Alaska, Human and Ecological Risk Assessment: An International Journal, 27:1, 227-257,
340 DOI: 10.1080/10807039.2019.1706151
341 Gough, L.P., R.C. Severson, and H.T. Shacklette. 1988. Element Concentrations in Soils and
342 Other Surficial Materials of Alaska. US Geological Survey Professional Paper 1458.
343 Hanley, Valerie. 2020. Staff Toxicologist at The State of California Department of Toxic Substances
344 Control. Personal Communication.
345 Hawaii Department of Health. 2008. Tier 2 action levels for arsenic (update to August 2006
346 memorandum). Health Hazard Evaluation and Emergency Response Office.
347 https://health.hawaii.gov/heer/files/2019/11/hdoharsenicsoilactionlevelsnov2011revsept2012-1.pdf.
348 Health Canada. 2017. Federal Contaminated Site Risk Assessment in Canada; Supplemental
349 Guidance on Human Health Risk Assessment of Oral Bioavailability of Substances in Soil and Soil-Like
350 Media 2017. Pub.: 170180. https://www.canada.ca/en/health-canada/services/environmental-workplace-
351 health/reports-publications/contaminated-sites/federal-contaminated-site-risk-assessment-canada-
352 supplemental-guidance-human-health-risk-assessment-oral-bioavailability.html

International Organization for Standardization (ISO). 2018. Soil Quality – Assessment of human exposure from ingestion of soil and soil material – procedure for the estimation of the human bioaccessibility/bioavailability of metals in soil. ISO 17924:2018.

Interstate Technology Regulatory Council (ITRC). 2017. Bioavailability of Contaminants in Soil. https://bcs-1.itrcweb.org/

Karna R.R., M. Noerpel, A.R. Betts, and K.G. Scheckel. 2017. Lead and Arsenic Bioaccessibility and Speciation as a Function of Soil Particle Size. J. Environ. Quality. 46: 1225- 1235.

Koch, I., KJ Reimer, MI. Bakker, NT Basta, MR Cave, S Denys, M Dodd, BA Hale, R Irwin, YW Lowney, MM. Moore, V Paquin, PE Rasmussen, T Repaso-Subang, GL Stephenson, SD Siciliano, J Wragg, GJ Zagury. 2013. Variability of bioaccessibility results using seventeen different methods on a standard reference material, NIST 2710. Journal of Environmental Science and Health, Part A: 48, 641–655.

Li, Y., E. Padoan, F Ajmone-Marsan. 2021. Soil particle size fraction and potentially toxic elements bioaccessibility: A review. Ecotoxicology and Environmental Safety 209. https://doi.org/10.1016/j.ecoenv.2020.111806

Liang, S., D.X. Guan, J. Li, C.Y. Zhou, J. Luo, L.Q. Ma. 2016, Effect of aging on bioaccessibility of arsenic and lead in soils. Chemosphere. 151: 94-100. ISSN 0045-6535. https://doi.org/10.1016/j.chemosphere.2016.02.070. (http://www.sciencedirect.com/science/article/pii/S0045653516302302)

Ljung, K., A. Oomen, M. Duits, O. Selinus, M. Berglund. 2007. Bioaccessibility of metals in urban playground soils. Journal of Environ. Sci. And Health. Part A. 42:9, 1241 – 1250. DOI: 10.1080/10934520701435684Ma, J., Y. Li. Y. Liu, C. Lin, H. Cheng. 019. Effects of soil particle size on metal bioaccessibility and health risk assessment. Ecotoxicol. Environ. Saf. 186, 109748. DOI: 10.1016/j.ecoenv.2019.109748.

Menzie, CA, B Southworth, G Stephenson, N Feisthauer. 2008. The importance of understanding the chemical form of a metal in the environment: the case of barium sulfate (Barite). Human and Ecological Risk Assessment: An International Journal,14:5,974 — 991. http://dx.doi.org/10.1080/10807030802387622

Menzie, CA., LM Ziccardi, YW Lowney, A. Fairbrother, S.S. Shock, J.S. Tusji, D. Hamai, D. Proctor, E. Henry, S.H. Su, M.W. Kierski, M.E. McArdle, L.J. Yost. 2009. Importance of considering the framework principles in risk assessment for metals. Environ. Sci. Technol. 43(22):8478-8482.

Perryman, C.R., J. Wirsing, K.A. Bennett, O. Brennick, P.L. Perry, N. Williamson, J.G. Ernakovich. 2020 Heavy metals in the Arctic: Distribution and enrichment of five metals in Alaskan soils. PLoS ONE 15(6): e0233297. https://doi.org/10.1371/journal.pone.0233297.

Rieuwerts, J.S., I. Thornton, M.E. Farago, M.R. Ashmore. 1998. Factors influencing metal bioavailability in soils: preliminary investigations for the development of a critical loads approach for metals, Chemical Speciation & Bioavailability, 10:2, 61-75, DOI: 10.3184/095422998782775835

Ruby, M.V. and Y.W. Lowney. 2012. Selective soil particle adherence to hands: implications for understanding oral exposure to soil contaminants. Environ Sci Technol. 4;46(23):12759-71. doi: 10.1021/es302473q. PMID: 23148503.

Ruby, M.V., R. Schoof, W. Brattin, M. Goldade, G. Post, M. Harnois, D.E. Mosby, S.W. Casteel, W. Berti, M. Carpenter, D. Edwards, D. Cragin and W. Chappell. 1999. Advances in Evaluating the Oral Bioavailability of Inorganics in Soil for Use in Human Health Risk Assessment. Env Sci Technol. 33, 3697-3705.

Rudnika-Kepa, P., and A Zaborska. 2021. Sources, fate and distribution of inorganic contaminants in the Svalbard area, representative of a typical Arctic critical environment–a review. Environ Monit Assess (2021) 193: 724

Ryan, JA, KG Scheckel, K. G., WR Berti, SL Brown, SW Casteel, RL Chaney, J Hallfrisch, M Doolan, P Grevatt, M Maddaloni, D Mosby. 2004. Reducing children's risk from lead in soil. Environ. Sci. Technol. 38: 18A–24A.

Scheckel, KG and JA Ryan. 2004. Spectroscopic speciation and quantification of lead in phosphate-amended soils. J. Environ. Qual. 33: 1288–1295.

Scheckel, K.G., J.A. Ryan, D. Allen, and N.V. Lescano. 2005. Determining speciation of Pb in phosphate-amended soils: Method limitations. Sci. Total Environ. 350: 261–272.

Scheckel, KG, G.L. Diamond, M.F. Burgess, J.M. Klotzbach, M. Maddaloni, B.W. Miller, C.R. Partridge & S.M. Serda. 2013 2019?. Amending Soils With Phosphate As Means To Mitigate Soil Lead Hazard: A Critical Review Of The State Of The Science. Journal of Toxicology and Environmental Health, Part B: Critical Reviews, 16:6, 337-380 http://dx.doi.org/10.1080/10937404.2013.825216

Schoof, R. 2003. Final Guide for Incorporating Bioavailability Adjustments into Human Health and Ecological Risk Assessments at Department of Defense Facilities. Part 2: Technical Background Document for Assessing Metals Bioavailability. Update prepared for Tri-Service Ecological Risk Assessment Workgroup.

Schroder, JL, NT Basta, J Si, SW Casteel, T Evans, M Payton 2003. In Vitro Gastrointestinal Method to Estimate Relative Bioavailable Cadmium in Contaminated Soil. Environ. Sci. Technol. 37, 1365-1370.

Shock, S.S., B.A. Bessinger, Y.W. Lowney, J.L. Clark. 2007. Assessment of the solubility and bioaccessibility of barium and aluminum in soils affected by mine dust deposition. Environ. Sci. Technol. 41, 4813-4820.

Sloan, J. J., R. H. Dowdy, M. S. Dolan, and D. R. Linden. 1997. Long-Term Effects of Biosolids Applications on Heavy Metal Bioavailability in Agricultural Soils. J. Environ. Qual. 26:966-974

Schroder et al. 2003??

Tregubova, P., G Koptsik, A. Stepanov, S. Koptsik, and G. Spiers. 2021. Organic amendments potentially stabilize metals in smelter contaminated Arctic soils: An incubation study. Heliyon 7(1); E06022. https://doi.org/10.1016/j.heliyon.2021.e06022https://doi.org/10.1016/j.heliyon.2021.e06022

428 Qin, J., O Nworie, C. Lin. 2016. Particle size effects on bioaccessible amounts of ingestible soil-
429 borne toxic elements. Chemosphere. Vol 159; 442-448.
430 https://doi.org/10.1016/j.chemosphere.2016.06.034
431 U.S. EPA. 1998. Guidelines for Ecological Risk Assessment. Risk Assessment Forum. EPA/630/R-
432 95/002F.
433 U.S. EPA. 2007. Guidance for evaluating the oral bioavailability of metals in soils for use in human
434 health risk assessment. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency
435 Response: Washington, DC. OSWER 9285.7-80.
436 U.S. EPA. 2007a. Estimation of relative bioavailability of lead in soil and soil-like materials using in
437 vivo and in vitro methods. OSWER 9285.7-77. U.S. Environmental Protection Agency, Washington, DC.
438 U.S. EPA. 2007b. Framework for metals risk assessment. Office of the Science Advisor. Risk
439 Assessment Forum. EPA 120/E-07/001.
440 U.S. EPA. 2007c. Short sheet: Estimating the soil lead concentration term for the Integrated Exposure
441 Uptake Biokinetic (IEUBK) Model. September 2007. Office of Solid Waste and Emergency Response
442 (OSWER) 9200.1-78.
443 U.S. EPA. 2016. Recommendations for Sieving Soil and dust Samples at Lead Sites for Assessment
444 of Incidental Ingestion. OLEM Directive 9200.1-128. July 1. United States Environmental Protection
445 Agency, Office of Solid Waste and Emergency Response, Washington, D.C.
446 U.S. EPA. 2017. Memorandum from Schatzi Fitz-James, Acting Director to Superfund National
447 Program Managers, Regions 1-10. Release of standard operating procedure for an in vitro
448 bioaccessibility assay for lead and arsenic in soil and validation assessment of the in vitro arsenic
449 bioaccessibility assay for predicting RBA of arsenic in soils and soil-like materials. Office of Land and
450 Emergency Management, Office of Superfund Remediation and Technology Innovation (OSRTI).
451 https://semspub.epa.gov/work/HQ/100000153.pdf

U.S. EPA. 2017. Standard operating procedure for an in vitro bioaccessibility assay for lead and arsenic in soil. EPA OLEM 9200.2-164. April 20, 2017. https://clu-in.org/download/contaminantfocus/arsenic/arsenic-SOP-OLEM-9200.2-164.pdf

Violante, A., V. Cozzolino, L. Perelomov, A.G. Caporale, and M. Pigna. 2010 Mobility and bioavailability of heavy metals and metalloids in soil environments. J. Soil. Sci. Plant Nutr. 10 (3): 268 - 292 (2010). DOI: 10.4067/S0718-95162010000100005

Whitacre, S., N Basta, B Stevens, V Hanley, R Anderson, K Scheckel. 2017. Modification of an existing in vitro method to predict relative bioavailable arsenic in soil. Chemosphere 180, 545-552.

Xu, Y., B. Seshadri, N. Bolan, B. Sarkar, Y.S. Ok, W. Zhang, C. Rumpel, D. Sparks, M. Farrell, T. Hall, Z. Dong. 2019. Microbial functional diversity and carbon use feedback in soils as affected by heavy metals. Environment International. 125:478-488. ISSN 0160-4120, https://doi.org/10.1016/j.envint.2019.01.071. (http://www.sciencedirect.com/science/article/pii/S0160412018319329)

Yang Z, W. Fang, X. Lu, G.P. Sheng, D.E. Graham, L. Liang, S.D. Wullschleger, B. Gu. 2016. Warming increases methylmercury production in an Arctic soil. Environ Pollut. 214:504-509. doi: 10.1016/j.envpol.2016.04.069. PMID: 27131808.

7.	Appendix A	General comment	EPA has validated an IVBA assay for predicting soil arsenic and lead RBA for use in human health risk assessments, but has not done so for the other metals mentioned. The DEC risk assessment manual adopted in regulation clearly states that a default value of 100% is recommended for all chemicals except arsenic and lead. EPA has not validated IVBA assays for other metals in respect to human health. However, the information can be presented in the uncertainty section in a human health risk assessment and in applications for ecological risk assessments. The information regarding validations for lead and arsenic is discussed but it should be made clear that the application regarding quantitative risk assessment with the other metals is suggesting meeting 100% of the requirements in 18 AAC 75 without a validated method.	

Understood and agreed. EPA has validated the IVBA method only for As and Pb for quantitative use in risk assessment, as was stated in third paragraph of "Study Background" section. However, for the purposes of this study, the IVBA method was applied to Al and Ba as a tool to understand more about the behavior of these metals in the environment, and most recently to assess whether there have been changes over time in the stability of the metals in the arctic environment, not for any application to risk assessment. This is discussed in the Study Background:

This method has been validated for quantitative use in predicting relative oral bioavailability of Pb and arsenic (As) for human health risk assessment (U.S. EPA 2017). Other investigations have also established that the acidic extraction conditions used in EPA Method 1340 also generate data that are generally predictive of the bioavailability of cadmium (Cd), for which an International Organization for Standardization (ISO) Standard has been developed (ISO 2018; Schroder et al. 2003; Boros et al. 2017). Similarly, investigations by Health Canada indicate that a low pH extraction method, such as EPA Method 1340, results in the most conservative estimate of IVBA for zinc (Zn) (Koch et al. 2013). Therefore, while validated by U.S. EPA (2018) for Pb and As only, EPA Method 1340 can also provide screening information for the bioavailability of other metals (Menzie et al. 2008).

8.	Pg 40-01	Tables 1 and 2	The total metal concentration in the soil was performed by XRF, a screening value/ tool dependent upon correlation and calibration with the respective soil media. However, this estimated value was used to determine IVBA with a different analytical analysis for the extract. The extract was based off ICP-AES (2005) and ICP-AES (2018). The same laboratory approved method for the "soil and extract" from EPA metal analysis 6010D or 6020B or 7000 series as noted in DEC Field Sampling Guidance Oct. 2019 is recommended.

Thank you for the comment. Please note, the primary goal of the current IVBA evaluation of Al and Ba was specifically intended to understand changes over time. The initial effort, reported in Shock et al. (2007), used laboratory XRF results to calculate IVBA for these metals. Therefore, for this comparison to be meaningful, it was appropriate to base the IVBA calculations on total metal determination with XRF.

EPA Method 3050B for soil <u>digestion</u> may not recover (dissolve) most of the Al and Ba in Red Dog site soils. As reported by Shock et al. (2007), comparison of results from this standard EPA digestion method for assessing total metals in soil against data from XRF evaluation identified that the EPA method extracted between 0.1% and 100% of Ba from site samples and 10% to 32% of Al from site samples. This is irrespective of the analytical instrumentation used (e.g., EPA 6010D, 6020B or 7000 series). This was an important finding by Shock et al. (2007), who concluded the following:

Analytical Considerations for Estimating Bioavailability. This study illustrates that the type of analyses used to assess barium concentrations in sampled substrates can have significant impact on calculated bioaccessibility. The extractable barium (Method 3050B/ICP-OES) was only a minor fraction of the total (XRF) barium, and therefore underestimated total concentrations in the main waste road and gyro crusher dust samples, and to a lesser extent, in the tundra soil samples. This occurs because barium in the form of barite is recalcitrant to the standard soil digestion methods (i.e., acid digestion by EPA Method 3050B), whereas XRF analysis reports higher barium concentrations for these soil media (effectively reporting total concentrations). If barium bioaccessibility is calculated using concentrations measured from standard digestion/analysis methods, the resulting values will likely be higher than would be obtained using XRF analysis.

Said another way, soils and IVBA fluids are often evaluated with different instrumentation. Conventionally, IVBA for metals in soil involves assessment of total metals, often extraction/digestion EPA Methods 3050 or 3051, and IVBA with extraction methods specified in EPA Method 1340. Under EPA Method 3050 (total metals in sediment sludges and soils), ICP-AES is recommended. However, the method also states that "alternative determinative techniques may be used." Shock et al. (2007) provided a comparison of total concentrations of Al and Ba in soils from the Red Dog area based on analysis with EPA Method 3050 (with ICP-OES) and XRF. Their results demonstrated that EPA Method 3050 does not capture the total concentrations of these target metals present [Note, EPA Method 3050 specifically states that it is a strong acid digestion but "is not a total digestion technique for most samples"]. For example, Shock et al. reported that concentrations of Ba in the <250 particle size fraction for tundra soils via EPA Method 3050 ranged from 58% to 97% of the concentration reported by laboratory XAS (for other samples, Method 3050 recovered only <1% of total Ba in the sample), and suggests that results are due to the presence of insoluble barite, which is not solubilized by the digestion specified in EPA Method 3050. Similarly, for Al, Shock et al. report that concentrations determined via Method 3050 were 16% to 24% of those reported via XRF, a result of incomplete digestion of silicate minerals that would contain Al. Therefore, Shock et al. selected the XRF method for reporting total metal concentrations, and these were used as the basis for calculating bioaccessible Ba and Al.

For this evaluation of IVBA, XRF was used to assess total concentrations of Al and Ba to circumvent the potential incomplete extraction associated with EPA Method 3050B, and to generate results that are comparable against those reported by Shock et al. (2007) given that the primary goal of the effort was to allow comparison of samples from two different time points.

			The large bias range (e.g. Al = 152% to 388%) suggests it would be appropriate to include the standard deviation with the bias.

The values for range in bias was provided for discussion of implications from the QA/QC data. In this case, the bias is indicated by IVBA spiked with soluble aluminum, and the recovery values are 152% 199%, and 388% of the spiked concentration. The first two values represent IVBA extraction of a spiked soil, and the 388% value represents recovery of Al from a spiked IVBA fluid. Given the limited number of samples and that all values are disclosed, we did not provide the standard deviation of the bias. For clarity, we rearranged the text as follows:

Under the standard IVBA extraction methods there were "interferences" between components of the extraction fluid and the Al mass in that fluid (ACZ Laboratory personal communication). These interferences result in reported concentrations of Al in the extraction fluid that are biased high. Quality assurance (QA) data from 2018 showed that ICP-MS recovery of Al spiked into the IVBA extraction fluid was 152% to 388%, indicating the reported IVBA values are overestimated. Table 1 presents both the original, unadjusted IVBA values and values adjusted by a factor of 2.5 for the high bias (based on the average recovery across triplicate samples, 247%, or a factor of approximately 2.5). For samples collected in 2005 (reported by Shock et al., 2007), bias was not an issue because the IVBA fluid was analyzed using ICP-OES. For any future efforts related to determination of Al IVBA, this potential for bias should be considered in the selection of an analytical lab and the type of instrumentation. When adjusted for the analytical bias, the bioaccessibility of Al from the 2018 soil samples was the same or lower than that measured in samples from matched locations in 2005.

			Some of the details within the body of the tables are unclear. 1) Sample size should be presented (n=XX) 2) Since sample size is not presented it is unclear if "%" is based upon an average or a single sample (please note for clarity). DEC regulation is based on maximum or approved 95% upper average concentrations to soil.

EPA Method 1340 for assessing the IVBA of Pb and As in soils specifies QA/QC measures that include blanks, spikes, and replicates, but does not indicate the need for replicate extraction of all soil samples. The data presented represent individual samples from each location. Replicate samples included in the extraction process indicated good reproducibility of extraction results for either soil particle size fraction. Consistent with EPA Method 1340 for IVBA analysis, individual data points presented do not represent averages of replicates.

All soil concentrations that were previously incorporated into the 2007 risk assessment process represent values consistent with DEC regulation.

			3) The raw data that were used in creating the table should be provided, and either cited if from prior reports or the actual data provided in a separate attachment.	

Please find an attachment with the raw data that were used for creating the table.

Table 1: Aluminum IVBA results for 2018 Red Dog samples

Sample Identifier	Grain Size	Solid:Fluid Ratio	Total Conc. In Soil[a] (mg/kg)	Mass of Soil Tested (g)	Mass of Analyte in Soil Extracted (mg)	Conc. of Analyte in Extract (mg/L)	Mass of Analyte in Extract (mg)	Total Conc. in Soil by XRF[b] (mg/kg)	Bioaccessibility (%)				
									IVBA using Total by XRF (%)	Bias-Adj IVBA using Total by XRF (%)	IVBA using Total by 3050b (%)	Bias-Adj IVBA using Total by 3050b (%)	Ratio of IVBA <2mm/<250µm
<2mm Particle Size Fraction													
TS-REF-3-COMPOSITE	<2 mm	1:100	11900	0.999	11.89	8.4	0.84	46400	1.8	0.7	7.1	2.8	1.1
TS-REF-7/TS-REF-11 COMPOSITE	<2 mm	1:100	2870	1.001	2.87	7.5	0.75		--		26.1	10.4	0.8
TT3-0010 COMPOSITE	<2 mm	1:100	2920	1.002	2.93	1.9	0.19	14000	1.4	0.5	6.5	2.6	1.2
TT3-0100 COMPOSITE	<2 mm	1:100	1490	1.000	1.49	2.0	0.20	--	--	--	13.4	5.4	1.1
TT3-1000 COMPOSITE	<2 mm	1:100	809	1.000	0.81	3.3	0.33	--	--	--	40.8	16.3	0.9
TT5-0010 COMPOSITE	<2 mm	1:100	7780	1.003	7.80	3.6	0.36	38600	0.9	0.4	4.6	1.8	1.1
TT5-2000 COMPOSITE	<2 mm	1:100	1020	0.997	1.02	7.0	0.70	--	--	--	68.8	27.5	1.0
TT7-0010 COMPOSITE	<2 mm	1:100	5740	1.002	5.75	14.8	1.48	26800	5.5	2.2	25.7	10.3	1.1
TT8-0010 COMPOSITE	<2 mm	1:100	5600	1.000	5.60	2.7	0.27	26200	1.0	0.4	4.8	1.9	1.1
TT8-0100 COMPOSITE	<2 mm	1:100	3070	1.003	3.08	3.2	0.32	13500	2.4	0.9	10.4	4.2	1.0
TT8-0800/TT8-0900-TT8-1000 COM	<2 mm	1:100	726	0.999	0.73	3.1	0.31	--	--	--	42.7	17.1	0.9
18-289 (Y Road Surface)	<2 mm	1:100	12800	1.003	12.84	2.8	0.28	65600	0.4	0.2	2.2	0.9	0.7
18-290 (R-Boundary Road Surface)	<2 mm	1:100	2050	0.999	2.05	0.7	0.07	9600	0.7	0.3	0.0	0.0	0.0
18-291 (MS-2 Road Surface)	<2 mm	1:100	7040	1.000	7.04	1.6	0.16	38700	0.4	0.2	2.3	0.9	0.8
18-292 (Zinc concentrate)	<2 mm	1:100	80	1.000	0.08	0.3	0.03	500	6.0	2.4	40.0	16.0	--
18-293 (Lead concentrate)	<2 mm	1:100	138	1.002	0.14	0.3	0.03	850	3.5	1.4	20.0	8.0	--
			0										
<250µm Particle Size Fraction			0										
TS-REF-3-COMPOSITE	<250 µm	1:100	11600	1.002	11.62	7.41	0.741	46900	1.6	0.6	6.4	2.6	
TS-REF-7/TS-REF-11 COMPOSITE	<250 µm	1:100	2350	0.999	2.35	7.72	0.772	--	--		32.9	13.2	
TT3-0010 COMPOSITE	<250 µm	1:100	3170	1.001	3.17	1.78	0.178	13800	1.3	0.5	5.6	2.2	
TT3-0100 COMPOSITE	<250 µm	1:100	1740	0.998	1.74	2.16	0.216	--	--	--	12.4	5.0	
TT3-1000 COMPOSITE	<250 µm	1:100	768	0.999	0.77	3.47	0.347	--	--	--	45.2	18.1	
TT5-0010 COMPOSITE	<250 µm	1:100	7580	0.999	7.57	3.30	0.330	43400	0.8	0.3	4.4	1.7	
TT5-2000 COMPOSITE	<250 µm	1:100	1020	1.000	1.02	7.13	0.713	--	--	--	69.9	28.0	
TT7-0010 COMPOSITE	<250 µm	1:100	6000	1.003	6.02	14.3	1.43	26800	5.3	2.1	23.8	9.5	
TT8-0010 COMPOSITE	<250 µm	1:100	5260	1.004	5.28	2.39	0.239	26400	0.9	0.4	4.5	1.8	
TT8-0100 COMPOSITE	<250 µm	1:100	3350	1.000	3.35	3.40	0.340	16100	2.1	0.8	10.1	4.1	
TT8-0800/TT8-0900-TT8-1000 COM	<250 µm	1:100	911	0.997	0.91	4.11	0.411	--	--		45.3	18.1	
18-289 (Y Road Surface)	<250 µm	1:100	13400	0.998	13.37	4.28	0.428	58700	0.7	0.3	3.2	1.3	
18-290 (R-Boundary Road Surface)	<250 µm	1:100	2960	0.998	2.95	1.65	0.165	20400	0.8	0.3	5.6	2.2	
18-291 (MS-2 Road Surface)	<250 µm	1:100	9430	0.998	9.41	2.81	0.281	46500	0.6	0.2	3.0	1.2	
18-292 (Zinc concentrate)	<250 µm	1:100	79	1.001	0.08	U	U	500	--	--	--	--	
18-293 (Lead concentrate)	<250 µm	1:100	168	1.001	0.17	U	U	900	--	--	--	--	

Note:

[a] Total concentration by 3050b analysis conducted by ACZ Laboratories

[b] IVBA result calculated using total metals result by x-ray fluorescence at The Mineral Lab.

--: Not Reported

Table 2: Aluminum QA sample results from in vitro aluminum bioaccessibility testing of 2018 soil samples

Grain Size	ACZ ID	Type	Description	Extraction Date	QC Conc.	Sample Conc.	Measured Conc.	Units	Percent Recovery (%)	Acceptable Range	Comments	Percent Recovery Recalc (%) [a]
IVBA EXTRACTION												
<2mm	WG470898ICB	ICB	Blank	4/24/2019			U	mg/L		<0.015		
<2mm	WG470898CCB1	CCB	Blank	4/24/2019			U	mg/L		<0.015		
<2mm	WG470898CCB2	CCB	Blank	4/24/2019			U	mg/L		<0.015		
<2mm	WG470898CCB3	CCB	Blank	4/24/2019			U	mg/L		<0.015		
<2mm	WG470417LFB	LFB	Spiked IVBA Fluid	4/24/2019	1.0013		3.89	mg/L	388	80-120%	Outside range	388
<2mm	L51008-03MS	MS	Spiked Soil (L51008-03)	4/24/2019	1.0013	1.9	4.42	mg/L	252	75-125%	Outside range	152
<2mm	L51008-13MS	MS	Spiked Soil (L51008-13)	4/24/2019	1.0013	0.7	3.38	mg/L	268	75-125%	Outside range	199
<2mm	L51008-01DUP	DUP	Sample Duplicate	4/24/2019		8.4	8.51	mg/L	101	80-120%		
<2mm	L51008-12DUP	DUP	Sample Duplicate	4/24/2019		2.8	2.8	mg/L	100	80-120%		
<2mm	L51008-06SDL	SDL	Serial Dilution	4/24/2019		3.6	3.8	mg/L	106	90-110%		
<2mm	WG470417PBS	PBS	Soil Blank	4/24/2019			U	mg/L		<0.3		
<2mm	WG470898ICV	ICV	Standard	4/24/2019	0.1		0.0965	mg/L	97	90-110%		
<2mm	WG470898PQV	PQV	Standard	4/24/2019	0.0150195		0.0141	mg/L	94	70-130%		
<2mm	WG470898ICSAB	ICSAB	Standard	4/24/2019	50.170026		46.8947	mg/L	93	80-120%		
<2mm	WG470898CCV1	CCV	Standard	4/24/2019	0.50065		0.4957	mg/L	99	90-110%		
<2mm	WG470898CCV2	CCV	Standard	4/24/2019	0.50065		0.4919	mg/L	98	90-110%		
<2mm	WG470898CCV3	CCV	Standard	4/24/2019	0.50065		0.5049	mg/L	101	90-110%		
TOTAL METAL (3050)												
<2mm	WG470618ICB	ICB	Blank	4/19/2019			U	mg/L		<0.015		
<2mm	WG470618CCB1	CCB	Blank	4/19/2019			U	mg/L		<0.015		
<2mm	WG470618CCB2	CCB	Blank	4/19/2019			U	mg/L		<0.015		
<2mm	WG470618CCB3	CCB	Blank	4/19/2019			U	mg/L		<0.015		
<2mm	WG470959ICB	ICB	Blank	4/25/2019			U	mg/L		<0.015		
<2mm	WG470959CCB1	CCB	Blank	4/25/2019			U	mg/L		<0.015		
<2mm	WG470959CCB2	CCB	Blank	4/25/2019			U	mg/L		<0.015		
<2mm	WG470959CCB3	CCB	Blank	4/25/2019			U	mg/L		<0.015		
<2mm	L51008-16MS	MS	Spiked Soil (L51008-16)	4/19/2019	25.0325	138	176.1	mg/Kg	152	75-125%	Outside range	108
<2mm	L51008-16MSD	MSD	Spiked Soil (L51008-16) Dup	4/19/2019	25.0325	138	178.3	mg/Kg	161	75-125%	Outside range	109
<2mm	L51008-16MS	MS	Matrix Spike (clean soil)	4/25/2019	5.0065	U	U	mg/Kg	0	75-125%	Outside range	
<2mm	L51008-16MSD	MSD	Matrix Spike (clean soil)	4/25/2019	5.0065	U	U	mg/Kg	0	75-125%	Outside range	
<2mm	L51008-04SDL	SDL	Serial Dilution	4/19/2019		1460	1422	mg/Kg	97	90-110%		
<2mm	L51008-03SDL	SDL	Serial Dilution	4/25/2019		2920	2932.5	mg/Kg	100	90-110%		
<2mm	WG470471PBS	PBS	Soil blank	4/19/2019			U	mg/Kg		<9		
<2mm	WG470471PBS	PBS	Soil blank	4/25/2019			U	mg/Kg		<9		
<2mm	WG470471LCSS	LCSS	Soil Standard	4/19/2019	8360		8366	mg/Kg	100	4160-12600		
<2mm	WG470471LCSSD	LCSSD	Soil Standard	4/19/2019	8360		8661	mg/Kg	104	4160-12600		
<2mm	WG470471LCSS	LCSS	Soil Standard	4/25/2019	8360		8487	mg/Kg	102	4160-12600		
<2mm	WG470471LCSSD	LCSSD	Soil Standard	4/25/2019	8360		8466	mg/Kg	101	4160-12600		
<2mm	WG470618ICV	ICV	Standard	4/19/2019	0.1		0.0957	mg/L	96	90-110%		
<2mm	WG470618PQV	PQV	Standard	4/19/2019	0.0150195		0.0144	mg/L	96	70-130%		
<2mm	WG470618ICSAB	ICSAB	Standard	4/19/2019	50.170026		47.0836	mg/L	94	80-120%		
<2mm	WG470618CCV1	CCV	Standard	4/19/2019	0.50065		0.4963	mg/L	99	90-110%		

Table 2: Aluminum QA sample results from in vitro aluminum bioaccessibility testing of 2018 soil samples

Grain Size	ACZ ID	Type	Description	Extraction Date	QC Conc.	Sample Conc.	Measured Conc.	Units	Percent Recovery (%)	Acceptable Range	Comments	Percent Recovery Recalc (%) [a]
<2mm	WG470618CCV2	CCV	Standard	4/19/2019	0.50065		0.5064	mg/L	101	90-110%		
<2mm	WG470618CCV3	CCV	Standard	4/19/2019	0.50065		0.524	mg/L	105	90-110%		
<2mm	WG470959ICV	ICV	Standard	4/25/2019	0.1		0.0962	mg/L	96	90-110%		
<2mm	WG470959PQV	PQV	Standard	4/25/2019	0.0150195		0.0124	mg/L	83	70-130%		
<2mm	WG470959ICSAB	ICSAB	Standard	4/25/2019	50.170026		47.325	mg/L	94	80-120%		
<2mm	WG470959CCV1	CCV	Standard	4/25/2019	0.50065		0.4999	mg/L	100	90-110%		
<2mm	WG470959CCV2	CCV	Standard	4/25/2019	0.50065		0.5114	mg/L	102	90-110%		
<2mm	WG470959CCV3	CCV	Standard	4/25/2019	0.50065		0.4976	mg/L	99	90-110%		
IVBA EXTRACTION												
<250um	WG471151ICB	ICB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG471151CCB1	CCB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG471151CCB2	CCB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG471151CCB3	CCB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG470840LFB	LFB	Spiked IVBA Fluid	4/29/2019	1.0013		2.668	mg/L	266	80-120%	Outside range	266
<250um	L51009-03MS	MS	Spiked Soil (L51009-03)	4/29/2019	1.0013	1.78	4.283	mg/L	250	75-125%	Outside range	154
<250um	L51009-16MS	MS	Spiked Soil (L51009-16)	4/29/2019	1.0013	U	3.4	mg/L	340	75-125%	Outside range	340
<250um	L51009-01DUP	DUP	Sample Duplicate	4/29/2019		7.41	7.517	mg/L	101	20		
<250um	L51009-15DUP	DUP	Sample Duplicate	4/29/2019		U	U	mg/L		80-120%		
<250um	L51009-06SDL	SDL	Serial Dilution	4/29/2019		3.3	3.715	mg/L	113	80-120%		
<250um	WG470840PBS	PBS	Soil Blank	4/29/2019			U	mg/L		<0.09		
<250um	WG471151ICV	ICV	Standard	4/29/2019	0.1		0.0933	mg/L	93	90-110%		
<250um	WG471151PQV	PQV	Standard	4/29/2019	0.0150195		0.0139	mg/L	93	70-130%		
<250um	WG471151ICSAB	ICSAB	Standard	4/29/2019	50.170026		48.3641	mg/L	96	80-120%		
<250um	WG471151CCV1	CCV	Standard	4/29/2019	0.50065		0.5025	mg/L	100	90-110%		
<250um	WG471151CCV2	CCV	Standard	4/29/2019	0.50065		0.5054	mg/L	101	90-110%		
<250um	WG471151CCV3	CCV	Standard	4/29/2019	0.50065		0.5082	mg/L	102	90-110%		
TOTAL METAL (3050)												
<250um	WG471030ICB	ICB	Blank	4/25/2019			U	mg/L		<0.015		
<250um	WG471030CCB1	CCB	Blank	4/25/2019			U	mg/L		<0.015		
<250um	WG471030CCB2	CCB	Blank	4/25/2019			U	mg/L		<0.015		
<250um	WG471030CCB3	CCB	Blank	4/25/2019			U	mg/L		<0.015		
<250um	WG471219ICB	ICB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG471219CCB1	CCB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG471219CCB2	CCB	Blank	4/29/2019			U	mg/L		<0.015		
<250um	WG470762LFB2	LFB	spiked 3050 fluid	4/25/2019	0.050065		0.0476	mg/Kg	95	80-120%		
<250um	WG470762LFBD2	LFBD	spiked 3050 fluid	4/25/2019	0.050065		0.0479	mg/Kg	96	80-120%		
<250um	L51009-09MS	MS	Spiked Soil (L51009-09)	4/25/2019	25.0325	5510	5842.8	mg/Kg	1329	75-125%	Outside range	106
<250um	L51009-09MSD	MSD	Spiked Soil (L51009-09) Dup	4/25/2019	25.0325	5510	5663.5	mg/Kg	613	75-125%	Outside range	102
<250um	L51009-09MS	MS	Spiked Soil (L51009-09)	4/29/2019	25	5260	5648	mg/Kg	1552	75-125%	Outside range	107
<250um	L51009-09MSD	MSD	Spiked Soil (L51009-09) Dup	4/29/2019	25	5260	5609	mg/Kg	1396	75-125%	Outside range	106
<250um	L51009-03SDL	SDL	Serial Dilution	4/25/2019		3170	2971	mg/Kg	94	90-110%		
<250um	L51009-11SDL	SDL	Serial Dilution	4/29/2019		1040	1037	mg/Kg	100	90-110%		
<250um	WG470762PBS	PBS	Soil blank	4/25/2019			U	mg/Kg		<9		

Table 2: Aluminum QA sample results from in vitro aluminum bioaccessibility testing of 2018 soil samples

Grain Size	ACZ ID	Type	Description	Extraction Date	QC Conc.	Sample Conc.	Measured Conc.	Units	Percent Recovery (%)	Acceptable Range	Comments	Percent Recovery Recalc (%) [a]
<250um	WG470843PBS	PBS	Soil blank	4/25/2019			U	mg/Kg		<9		
<250um	WG470843PBS	PBS	Soil blank	4/29/2019			U	mg/Kg		<9		
<250um	WG470762LCSS	LCSS	Soil Standard	4/25/2019	598		200.5	mg/Kg	34	179-239	Outside range	
<250um	WG470843LCSS	LCSS	Soil Standard	4/25/2019	8360		8412	mg/Kg	101	4160-12600		
<250um	WG470843LCSSD	LCSSD	Soil Standard	4/25/2019	8360		7813	mg/Kg	93	4160-12600		
<250um	WG470843LCSS	LCSS	Soil Standard	4/29/2019	8360		8853	mg/Kg	106	4160-12600		
<250um	WG470843LCSSD	LCSSD	Standard	4/29/2019	8360		8284	mg/Kg	99	4160-12600		
<250um	WG471030ICV	ICV	Standard	4/25/2019	0.1		0.0957	mg/L	96	90-110%		
<250um	WG471030PQV	PQV	Standard	4/25/2019	0.0150195		0.0137	mg/L	91	70-130%		
<250um	WG471030ICSAB	ICSAB	Standard	4/25/2019	50.170026		47.3803	mg/L	94	80-120%		
<250um	WG471030CCV1	CCV	Standard	4/25/2019	0.50065		0.4655	mg/L	93	90-110%		
<250um	WG471030CCV2	CCV	Standard	4/25/2019	0.50065		0.4677	mg/L	93	90-110%		
<250um	WG471030CCV3	CCV	Standard	4/25/2019	0.50065		0.4749	mg/L	95	90-110%		
<250um	WG471219ICV	ICV	Standard	4/29/2019	0.1		0.0942	mg/L	94	90-110%		
<250um	WG471219PQV	PQV	Standard	4/29/2019	0.0150195		0.0134	mg/L	89	70-130%		
<250um	WG471219ICSAB	ICSAB	Standard	4/29/2019	50.170026		42.4878	mg/L	85	80-120%		
<250um	WG471219CCV1	CCV	Standard	4/29/2019	0.50065		0.4886	mg/L	98	90-110%		
<250um	WG471219CCV2	CCV	Standard	4/29/2019	0.50065		0.4903	mg/L	98	90-110%		

[a] Alternate calculation to address failure to meet 4x criterion

Table 3: Barium IVBA results for 2018 Red Dog samples

Sample Identifier	Grain Size	Solid:Fluid Ratio	Total Conc. In Soil[a] (mg/kg)	Mass of Soil Tested (g)	Mass of Analyte in Soil Extracted (mg)	Conc. of Analyte in Extract (mg/L)	Mass of Analyte in Extract (mg)	Total Conc. in Soil by XRF[b] (mg/kg)	Bioaccessibility (%)		Ratio of IVBA <2mm/<250µm
									IVBA using Total by XRF (%)	IVBA using Total by 3050b (%)	
<2mm Particle Size Fraction											
TS-REF-3-COMPOSITE	<2 mm	1:100	320	0.999	0.32	1.78	0.18	700	30	56	0.9
TS-REF-7/TS-REF-11 COMPOSITE	<2 mm	1:100	302	1.001	0.30	2.59	0.26	--		86	1.0
TT3-0010 COMPOSITE	<2 mm	1:100	2250	1.002	2.25	6.50	0.65	3000	22	29	1.2
TT3-0100 COMPOSITE	<2 mm	1:100	883	1.000	0.88	4.39	0.44	--	--	50	1.0
TT3-1000 COMPOSITE	<2 mm	1:100	251	1.000	0.25	2.26	0.23	--	--	90	1.0
TT5-0010 COMPOSITE	<2 mm	1:100	2140	1.003	2.15	3.49	0.35	2900	12	16	1.0
TT5-2000 COMPOSITE	<2 mm	1:100	154	0.997	0.15	1.37	0.14	--	--	89	1.0
TT7-0010 COMPOSITE	<2 mm	1:100	3510	1.002	3.52	7.01	0.70	--	--	20	1.3
TT8-0010 COMPOSITE	<2 mm	1:100	1590	1.000	1.59	3.72	0.37	2100	18	23	1.1
TT8-0100 COMPOSITE	<2 mm	1:100	992	1.003	0.99	3.99	0.40	2100	19	40	1.1
TT8-0800/TT8-0900-TT8-1000 COM	<2 mm	1:100	203	0.999	0.20	1.79	0.18	--	--	88	1.0
18-289 (Y Road Surface)	<2 mm	1:100	5700	1.003	5.72	10.5	1.05	21400	5	18	1.3
18-290 (R-Boundary Road Surface)	<2 mm	1:100	1010	0.999	1.01	2.96	0.30	800	37	29	0.8
18-291 (MS-2 Road Surface)	<2 mm	1:100	452	1.000	0.45	1.97	0.20	1200	16	44	1.7
18-292 (Zinc concentrate)	<2 mm	1:100	105	1.000	0.11	1.45	0.15	7700	2	138	0.5
18-293 (Lead concentrate)	<2 mm	1:100	185	1.002	0.19	1.5	0.15	8900	2	81	0.9
<250µm Particle Size Fraction											
TS-REF-3-COMPOSITE	<250 µm	1:100	289	1.002	0.29	1.71	0.17	600	30	59	
TS-REF-7/TS-REF-11 COMPOSITE	<250 µm	1:100	301	0.999	0.30	2.65	0.27	--	--	88	
TT3-0010 COMPOSITE	<250 µm	1:100	2670	1.001	2.67	6.57	0.66	3200	21	25	
TT3-0100 COMPOSITE	<250 µm	1:100	927	0.998	0.93	4.59	0.46	--	--	50	
TT3-1000 COMPOSITE	<250 µm	1:100	237	0.999	0.24	2.15	0.22	--	--	91	
TT5-0010 COMPOSITE	<250 µm	1:100	2620	0.999	2.62	4.06	0.41	3000	14	16	
TT5-2000 COMPOSITE	<250 µm	1:100	153	1.000	0.15	1.41	0.14	--	--	92	
TT7-0010 COMPOSITE	<250 µm	1:100	4470	1.003	4.48	7.14	0.71	6300	11	16	
TT8-0010 COMPOSITE	<250 µm	1:100	1760	1.004	1.77	3.71	0.37	2200	17	21	
TT8-0100 COMPOSITE	<250 µm	1:100	1060	1.000	1.06	3.97	0.40	1900	21	37	
TT8-0800/TT8-0900-TT8-1000 COM	<250 µm	1:100	223	0.997	0.22	1.98	0.20	--	--	89	
18-289 (Y Road Surface)	<250 µm	1:100	6170	0.998	6.16	8.82	0.88	41000	2	14	
18-290 (R-Boundary Road Surface)	<250 µm	1:100	1330	0.998	1.33	5.01	0.50	2100	24	38	
18-291 (MS-2 Road Surface)	<250 µm	1:100	1330	0.998	1.33	3.5	0.35	1800	19	26	
18-292 (Zinc concentrate)	<250 µm	1:100	64.2	1.001	0.06	1.9	0.19	8200	2	296	
18-293 (Lead concentrate)	<250 µm	1:100	148	1.001	0.15	1.34	0.13	9580	1	90	

Note:

[a] Total concentration by 3050b analysis conducted by ACZ Laboratories

[b] IVBA result calculated using total metals result by x-ray fluorescence at The Mineral Lab.

--: Not Reported

Table 4: Barium QA sample results from in vitro barium bioaccessibility testing of 2018 soil samples

Grain Size	ACZ ID	Type	Description	Extraction Date	QC Conc.	Sample Conc.	Measured Conc.	Units	Percent Recovery (%)	Acceptable Range	Comments	Percent Recovery Recalc (%) [a]
IVBA EXTRACTION												
<2mm	WG470546ICB	ICB	Blank	4/18/2019			U	mg/L		<0.0015		
<2mm	WG470546CCB1	CCB	Blank	4/18/2019			U	mg/L		<0.0015		
<2mm	WG470546CCB2	CCB	Blank	4/18/2019			U	mg/L		<0.0015		
<2mm	WG470546CCB3	CCB	Blank	4/18/2019			U	mg/L		<0.0015		
<2mm	WG470956ICB	ICB	Blank	4/24/2019			U	mg/L		<0.0015		
<2mm	WG470956CCB1	CCB	Blank	4/24/2019			U	mg/L		<0.0015		
<2mm	WG470956CCB2	CCB	Blank	4/24/2019			U	mg/L		<0.0015		
<2mm	WG470417LFB	LFB	Spiked IVBA Fluid	4/18/2019	1.002		0.90272	mg/L	90	80-120%		
<2mm	WG470417LFB	LFB	Spiked IVBA Fluid	4/24/2019	1.002		0.9937	mg/L	99	80-120%		
<2mm	L51008-03MS	MS	Spiked Soil (L5-1008-03)	4/18/2019	1.002	5.86	6.89991	mg/L	104	75-125%		101
<2mm	L51008-03MS	MS	Spiked Soil (L5-1008-03)	4/24/2019	1.002	6.5	7.457	mg/L	96	75-125%		99
<2mm	L51008-13MS	MS	Spiked Soil (L5-1008-13)	4/18/2019	1.002	2.96	4.48979	mg/L	153	75-125%	Outside range	113
<2mm	L51008-13MS	MS	Spiked Soil (L5-1008-13)	4/24/2019	1.002	3.22	4.8453	mg/L	162	75-125%	Outside range	115
<2mm	L51008-01DUP	DUP	Sample Duplicate	4/18/2019		1.78	1.83013	mg/L	103	80-120%		
<2mm	L51008-12DUP	DUP	Sample Duplicate	4/18/2019		9.29	9.18908	mg/L	99	80-120%		
<2mm	L51008-01DUP	DUP	Sample Duplicate	4/24/2019		1.94	1.935	mg/L	100	80-120%		
<2mm	L51008-12DUP	DUP	Sample Duplicate	4/24/2019		10.5	10.289	mg/L	98	80-120%		
<2mm	L51008-06SDL	SDL	Serial Dilution	4/18/2019		3.49	3.5896	mg/L	103	90-110%		
<2mm	L51008-08SDL	SDL	Serial Dilution	4/24/2019		7.01	8.125	mg/L	116	90-110%		
<2mm	WG470417PBS	PBS	Soil blank	4/18/2019			0.00072	mg/L		<0.0015		
<2mm	WG470417PBS	PBS	Soil blank	4/24/2019			U	mg/L		<0.009		
<2mm	WG470546ICV	ICV	Standard	4/18/2019	0.05		0.05262	mg/L	105	90-110%		
<2mm	WG470546PQV	PQV	Standard	4/18/2019	0.002505		0.00224	mg/L	89	70-130%		
<2mm	WG470546ICSA	ICSA	Standard	4/18/2019			U	mg/L		<0.003		
<2mm	WG470546ICSAB	ICSAB	Standard	4/18/2019	0.02004		0.01978	mg/L	99	80-120%		
<2mm	WG470546CCV1	CCV	Standard	4/18/2019	0.2505		0.24197	mg/L	97	90-110%		
<2mm	WG470546CCV2	CCV	Standard	4/18/2019	0.2505		0.23873	mg/L	95	90-110%		
<2mm	WG470546CCV3	CCV	Standard	4/18/2019	0.2505		0.23069	mg/L	92	90-110%		
<2mm	WG470956ICV	ICV	Standard	4/24/2019	0.05		0.0506	mg/L	101	90-110%		
<2mm	WG470956PQV	PQV	Standard	4/24/2019	0.002505		0.00234	mg/L	93	70-130%		
<2mm	WG470956ICSA	ICSA	Standard	4/24/2019			U	mg/L		<0.003		
<2mm	WG470956ICSAB	ICSAB	Standard	4/24/2019	0.02004		0.02331	mg/L	116	80-120%		
<2mm	WG470956CCV1	CCV	Standard	4/24/2019	0.2505		0.25074	mg/L	100	90-110%		
<2mm	WG470956CCV2	CCV	Standard	4/24/2019	0.2505		0.25145	mg/L	100	90-110%		
Total Barium (3050)												
<2mm	WG470618ICB	ICB	Blank	4/19/2019			U	mg/L		<0.0015		
<2mm	WG470618CCB1	CCB	Blank	4/19/2019			U	mg/L		<0.0015		
<2mm	WG470618CCB2	CCB	Blank	4/19/2019			0.00088	mg/L		<0.0015		
<2mm	WG470618CCB3	CCB	Blank	4/19/2019			0.00102	mg/L		<0.0015		
<2mm	WG470959ICB	ICB	Blank	4/25/2019			U	mg/L		<0.0015		
<2mm	WG470959CCB1	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<2mm	WG470959CCB2	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<2mm	WG470959CCB3	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<2mm	L51008-16MS	MS	Spiked Soil (L51008-16)	4/19/2019	25.05	185	173.55	mg/Kg	-46	75-125%	Outside range	83
<2mm	L51008-16MSD	MSD	Spiked Soil (L51008-16) Dup	4/19/2019	25.05	185	153.87	mg/Kg	-124	75-125%	Outside range	73

Table 4: Barium QA sample results from in vitro barium bioaccessibility testing of 2018 soil samples

Grain Size	ACZ ID	Type	Description	Extraction Date	QC Conc.	Sample Conc.	Measured Conc.	Units	Percent Recovery (%)	Acceptable Range	Comments	Percent Recovery Recalc (%) [a]
<2mm	L51008-16MS	MS	Spiked Soil (L51008-16)	4/25/2019	5.01	100	U	mg/Kg	0	75-125%	Outside range	
<2mm	L51008-16MSD	MSD	Spiked Soil (L51008-16) Dup	4/25/2019	5.01	100	U	mg/Kg	0	75-125%	Outside range	
<2mm	L51008-04SDL	SDL	Serial Dilution	4/19/2019		911	877.75	mg/Kg	96	90-110%		
<2mm	L51008-03SDL	SDL	Serial Dilution	4/25/2019		2250	2283.7	mg/Kg	101	90-110%		
<2mm	WG470471PBS	PBS	Soil blank	4/19/2019			U	mg/Kg		<0.9		
<2mm	WG470471PBS	PBS	Soil blank	4/25/2019			U	mg/Kg		<0.9		
<2mm	WG470471LCSS	LCSS	Soil Standard	4/19/2019	270		299.6	mg/Kg	111	223-318		
<2mm	WG470471LCSSD	LCSSD	Soil Standard	4/19/2019	270		292.5	mg/Kg	108	223-318		
<2mm	WG470471LCSS	LCSS	Soil Standard	4/25/2019	270		267.9	mg/Kg	99	223-318		
<2mm	WG470471LCSSD	LCSSD	Soil Standard	4/25/2019	270		257.2	mg/Kg	95	223-318		
<2mm	WG470618ICV	ICV	Standard	4/19/2019	0.05		0.05473	mg/L	109	90-110%		
<2mm	WG470618PQV	PQV	Standard	4/19/2019	0.002505		0.00251	mg/L	100	70-130%		
<2mm	WG470618ICSA	ICSA	Standard	4/19/2019			U	mg/L		<0.003		
<2mm	WG470618ICSAB	ICSAB	Standard	4/19/2019	0.02004		0.02225	mg/L	111	80-120%		
<2mm	WG470618CCV1	CCV	Standard	4/19/2019	0.2505		0.24812	mg/L	99	90-110%		
<2mm	WG470618CCV2	CCV	Standard	4/19/2019	0.2505		0.24542	mg/L	98	90-110%		
<2mm	WG470618CCV3	CCV	Standard	4/19/2019	0.2505		0.2504	mg/L	100	90-110%		
<2mm	WG470959ICV	ICV	Standard	4/25/2019	0.05		0.05063	mg/L	101	90-110%		
<2mm	WG470959PQV	PQV	Standard	4/25/2019	0.002505		0.00223	mg/L	89	70-130%		
<2mm	WG470959ICSA	ICSA	Standard	4/25/2019			U	mg/L		<0.003		
<2mm	WG470959ICSAB	ICSAB	Standard	4/25/2019	0.02004		0.01915	mg/L	96	80-120%		
<2mm	WG470959CCV1	CCV	Standard	4/25/2019	0.2505		0.24461	mg/L	98	90-110%		
<2mm	WG470959CCV2	CCV	Standard	4/25/2019	0.2505		0.24709	mg/L	99	90-110%		
<2mm	WG470959CCV3	CCV	Standard	4/25/2019	0.2505		0.24218	mg/L	97	90-110%		
IVBA EXTRACTION												
<250um	WG471024ICB	ICB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471024CCB1	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471024CCB2	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471024CCB3	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471024CCB4	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG470840LFB	LFB	Spiked IVBA Fluid	4/25/2019	1.002		0.9481	mg/L	95	80-120%		
<250um	L51009-03MS	MS	Spiked Soil (L51009-03)	4/25/2019	1.002	6.57	7.3388	mg/L	77	75-125%		
<250um	L51009-16MS	MS	Spiked Soil (L51009-16)	4/25/2019	1.002	1.34	1.7829	mg/L	44	75-125%	Outside range	76
<250um	L51009-01DUP	DUP	Soil Dup	4/25/2019		1.71	1.7064	mg/L	100	80-120%		
<250um	L51009-15DUP	DUP	Soil Dup	4/25/2019		1.9	1.7834	mg/L	94	80-120%		
<250um	L51009-06SDL	SDL	Serial Dilution	4/25/2019		4.06	3.907	mg/L	96	90-110%		
<250um	WG470840PBS	PBS	Soil blank	4/25/2019			U	mg/L		<0.009		
<250um	WG471024ICV	ICV	Standard	4/25/2019	0.05		0.05097	mg/L	102	90-110%		
<250um	WG471024PQV	PQV	Standard	4/25/2019	0.002505		0.00223	mg/L	89	70-130%		
<250um	WG471024ICSA	ICSA	Standard	4/25/2019			U	mg/L		<0.003		
<250um	WG471024ICSAB	ICSAB	Standard	4/25/2019	0.02004		0.01855	mg/L	93	80-120%		
<250um	WG471024CCV1	CCV	Standard	4/25/2019	0.2505		0.25291	mg/L	101	90-110%		
<250um	WG471024CCV2	CCV	Standard	4/25/2019	0.2505		0.25367	mg/L	101	90-110%		
<250um	WG471024CCV3	CCV	Standard	4/25/2019	0.2505		0.24974	mg/L	100	90-110%		
<250um	WG471024CCV4	CCV	Standard	4/25/2019	0.2505		0.24784	mg/L	99	90-110%		

Table 4: Barium QA sample results from in vitro barium bioaccessibility testing of 2018 soil samples

Grain Size	ACZ ID	Type	Description	Extraction Date	QC Conc.	Sample Conc.	Measured Conc.	Units	Percent Recovery (%)	Acceptable Range	Comments	Percent Recovery Recalc (%) [a]
TOTAL BARIUM (3050)												
<250um	WG471030ICB	ICB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471030CCB1	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471030CCB2	CCB	Blank	4/25/2019			U	mg/L		<0.0015		
<250um	WG471030CCB3	CCB	Blank	4/25/2019			0.00071	mg/L		<0.0015		
<250um	WG471219ICB	ICB	Blank	4/29/2019			U	mg/L		<0.0015		
<250um	WG471219CCB1	CCB	Blank	4/29/2019			U	mg/L		<0.0015		
<250um	WG471219CCB2	CCB	Blank	4/29/2019			U	mg/L		<0.0015		
<250um	WG470762LFB2	LFB	Spiked IVBA Fluid	4/25/2019	0.0501		0.04564	mg/Kg	91	80-120%		
<250um	WG470762LFBD2	LFBD	Spiked IVBA Fluid	4/25/2019	0.0501		0.04656	mg/Kg	93	80-120%		
<250um	L51009-09MS	MS	Spiked Soil (L51009-09)	4/25/2019	25.05	1760	1821.97	mg/Kg	247	75-125%	Outside range	102
<250um	L51009-09MSD	MSD	Spiked Soil (L51009-09) Dup	4/25/2019	25.05	1760	1797.93	mg/Kg	151	75-125%	Outside range	101
<250um	L51009-09MS	MS	Spiked Soil (L51009-09)	4/29/2019	25	1730	1801	mg/Kg	284	75-125%	Outside range	103
<250um	L51009-09MSD	MSD	Spiked Soil (L51009-09) Dup	4/29/2019	25	1730	1824.2	mg/Kg	377	75-125%	Outside range	104
<250um	L51009-03SDL	SDL	Serial Dilution	4/25/2019		2570	2390.5	mg/Kg	93	90-110%		
<250um	L51009-11SDL	SDL	Serial Dilution	4/29/2019		272	267.35	mg/Kg	98	90-110%		
<250um	WG470762PBS	PBS	Soil blank	4/25/2019			U	mg/Kg		<0.9		
<250um	WG470843PBS	PBS	Soil blank	4/25/2019			U	mg/Kg		<0.9		
<250um	WG470843PBS	PBS	Soil blank	4/29/2019			U	mg/Kg		<0.9		
<250um	WG470843LCSS	LCSS	Soil Standard	4/25/2019	270		265.1	mg/Kg	98	223-318		
<250um	WG470843LCSSD	LCSSD	Soil Standard	4/25/2019	270		250.1	mg/Kg	93	223-318		
<250um	WG470843LCSS	LCSS	Soil Standard	4/29/2019	270		295.8	mg/Kg	110	223-318		
<250um	WG470843LCSSD	LCSSD	Soil Standard	4/29/2019	270		278.1	mg/Kg	103	223-318		
<250um	WG471030ICV	ICV	Standard	4/25/2019	0.05		0.05019	mg/L	100	90-110%		
<250um	WG471030PQV	PQV	Standard	4/25/2019	0.002505		0.00224	mg/L	89	70-130%		
<250um	WG471030ICSA	ICSA	Standard	4/25/2019			U	mg/L		<0.003		
<250um	WG471030ICSAB	ICSAB	Standard	4/25/2019	0.02004		0.01982	mg/L	99	80-120%		
<250um	WG471030CCV1	CCV	Standard	4/25/2019	0.2505		0.23729	mg/L	95	90-110%		
<250um	WG471030CCV2	CCV	Standard	4/25/2019	0.2505		0.2386	mg/L	95	90-110%		
<250um	WG471030CCV3	CCV	Standard	4/25/2019	0.2505		0.23479	mg/L	94	90-110%		
<250um	WG471219ICV	ICV	Standard	4/29/2019	0.05		0.05251	mg/L	105	90-110%		
<250um	WG471219PQV	PQV	Standard	4/29/2019	0.002505		0.00233	mg/L	93	70-130%		
<250um	WG471219ICSA	ICSA	Standard	4/29/2019	0.00055		0.00055	mg/L	100	<0.003		
<250um	WG471219ICSAB	ICSAB	Standard	4/29/2019	0.02004		0.02068	mg/L	103	80-120%		
<250um	WG471219CCV1	CCV	Standard	4/29/2019	0.2505		0.2452	mg/L	98	90-110%		
<250um	WG471219CCV2	CCV	Standard	4/29/2019	0.2505		0.24592	mg/L	98	90-110%		

[a] Alternate calculation to address failure to meet 4x criterion